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AIR MEDICAL SERVICE.

PHYSIOLOGICAL EFFECTS OF ALTITUDE.

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Altitude is a climatic condition that causes physiological changes which affect our bodily comforts. Among its variables are lowered atmospheric pressure, partial pressure of oxygen, temperature and humidity; and increased intensity of sunshine and electrical conditions. While in the past the effects of altitude have been attributed to one or more of these variables (15), (37), (104), it is to-day recognized that the controlling element in the physiological reactions is the diminished partial pressure of oxygen and the consequent imperfect aeration of the arterial blood.

The altitude oxygen want is ascribed to two conditions. Primarily it is due to the imperfect saturation of the arterial blood with oxygen, which is the result of reduced atmospheric pressure; but secondarily it becomes temporarily more pronounced because of a chemical change in the blood that prevents as free a passage of oxygen into the tissues as is normally the case. This oxygen want may cause trouble in the body, which is usually soon offset by compensatory reactions that ultimately, if a residence be maintained, lead to acclimatization. The anoxemia, defined (45) as a condition in which the rate of supply of oxygen to the tissues is insufficient, means in many men a temporary slowing down of life.

Barcroft (6) has pointed out that acute anoxemia simulates drunkenness, while chronic anoxemia, which is an oxygen want, perhaps not very great, but that may be continued over months, simulates fatigue. He classifies the chronic types of anoxemia as the anoxic, anemic, and stagnant. In the first the pressure of oxygen in the blood is too low and the hemoglobin is not saturated to the normal extent; in the second the quantity of hemoglobin in the body is too small, but the oxygen pressure is normal; in the third the blood is normal, but supplied to the tissues in insufficient quantities. It is the anoxic type that occurs at high altitudes, and this, according to Barcroft, is the most difficult for the organism to circumvent, since the rate of delivery of oxygen to the tissues depends upon the pressure of oxygen in the blood.

The behavior of the organism under low oxygen depends upon four factors: 1, the suddenness with which the oxygen is decreased; 2, the extent to which it is decreased; 3, the length of time it is decreased; and 4, to some extent, upon the physical condition of the body. These should be recognized in any statement of symptoms of and compensations to altitude. Thus the conscious and outwardly appearing reactions experienced by the aviator and the mountaineer are, as a rule, quite unlike because of the speed as well as the extent of oxygen reduction. The compensations to altitude fall into two categories—namely, the emergency adjustments, based upon temporary functional changes, and the permanent, which, by profound alterations, result in acclimatization. The lowest altitude at which the temporary compensations occur will depend to a considerable extent upon the speed with which the ascent is made and the degree of response upon the height reached. The permanent adjustments require time, and their onset and amount will be determined by the first two factors.

The ability to compensate to the low oxygen tensions of high altitudes varies with the individual, and the adjustments may be more rapid and effective at one time than another. In repeated journeys to the summit of Pikes Peak the author has experienced several degrees of mountain sickness and at other times has escaped the malady. In the United States Army Air Service (2), (3), (68) the experience with the altitude classification test of low oxygen by rebreathing has shown that men who ordinarily compensate well to the low oxygen may pass through a period in which they do poorly. While the differences can not be entirely accounted for, yet without doubt they have many times been associated with health.

Much of our information regarding the effects of altitude has been obtained by methods of investigation that did not necessitate living on the mountains. Various researches (10) have shown that merely to subject the organism to a deficiency of oxygen calls forth the reactions characteristic of altitude. Lutz and Schneider (66) subjected men to low oxygen tensions produced in three ways—by low barometric pressure in a low-pressure chamber which was continuously supplied with fresh air; by a low percentage of oxygen caused by rebreathing air confined to a mechanism in which the normal atmospheric pressure was maintained and from which the carbon dioxide was removed; and by diluting the respired air with increasing amounts of nitrogen. By conducting experiments more or less parallel as to time, rate, and duration, they were able to prove that the circulatory, respiratory, and blood adaptive changes were practically identical in these three methods.

A study of altitude and anoxemia leads to the conclusion that much work has been partially or wholly futile because of unsatisfactory experimental methods. This lack has given a literature full of contradictory theories and conclusions. The space allotted by the editors of this journal makes it impossible to consider many interesting studies.

Only such as bear on recent work will be considered. The reader is referred to Cohnheim (17) and Zuntz, Loewy, Müllar, and Caspari (104) for helpful reviews of many topics.

Attention is called to the fact that expeditions have many times been made to altitudes that were too low to give a satisfactory response, and the time spent at the altitudes has often been too short for the adaptive changes to have progressed sufficiently to be measured. The process of acclimatization has been studied for altitudes only up to 15,000 feet. The most satisfactory returns have come from expeditions made to 14,000 feet or higher. The results obtained by a short sojourn at 6,000 to 10,000 feet have been, as a rule, unsatisfactory. Our knowledge of more acute oxygen want, as experienced in flying, includes altitudes up to those that cause unconsciousness.

The responses of the organism to the anoxemia of altitude involve the respiration, blood, and circulation, and are: 1, a fall in the alveolar carbon dioxide pressure and a rise in the alveolar oxygen pressure, which are associated with an increase in the ventilation of the lungs; 2, an increase in the percentage and the total amount of hemoglobin in the blood; 3, a modification in the proportion of acids and bases in the blood; and 4, an increase in the rate of heart beat, with which are also associated other circulatory changes. Each of these has been considered to be in the nature of a compensation, so that the tissues may be more adequately supplied with oxygen. The respiratory changes raise the oxygen pressure to which the blood is exposed; the increase in hemoglobin provides for more oxygen in a given unit volume of blood; the chemical changes provide the conditions for an adequate dissociation of oxyhemoglobin in the tissue capillaries; and it has been thought that the circulatory changes result in an increased volume of blood flow, which would raise, to a slight extent, the oxygen pressure in the tissues.

It has been found that under the conditions of flying the respiration and circulation are the first mechanisms to be stimulated, and they are almost equally sensitive to relatively low altitudes; while at higher altitudes the blood may also concentrate (42). During residence at a high altitude, the respiration is the first function affected and may even begin to change during the ascent. Ordinarily in the mountaineer the beginnings of the blood and circulatory changes are delayed by at least as much as 6 to 24 hours. There is evidence that the most temporary of the several changes are those affecting the circulatory system. In the interactions of the several physiologic functions concerned in acclimatization, the circulation alone tends to return to the low altitude normal; while the other functions continue on at the new levels as long as residence at the altitude is maintained.

SYMPTOMS NOTICEABLE AT HIGH ALTITUDES.

When anoxemia is produced gradually and rapidly as in an airplane ascent the effects are insidious and easily overlooked. In fact many aviators find it difficult to analyze their sensations and are not sure that altitudes produced any effect. This is because the most striking action is on the nervous system. The first effect is stimulation and results in a feeling of well-being, but this stage gradually and insensibly passes into sensory and mental dullness (3), (4), (12), (65). At 12,000 feet the aviator may be conscious of breathlessness, a little higher he feels muscular weakness when moving, there may be a headache and a tendency to Cheyne-Stokes breathing. As he continues to ascend memory and judgment are gradually impaired, while sight and hearing become dulled. Many men experience an overpowering desire to sleep, while fainting is not uncommon. Unfortunately the aviator often becomes possessed with fixed ideas and being unable to reason does foolish things. To then continue to ascend means loss of consciousness. Between 23,000 and 25,000 feet appears to be the upper altitude limit for consciousness for unacclimatized men.

There are after effects of an altitude flight that are of special interest, such as unusual fatigue, subnormal breathing in which the rate and depth are decreased, subnormal blood pressure, and headache.

The mountaineer ascends more slowly and, unlike the aviator, is liable to an attack of "mountain sickness." The first effect as in a rapid ascent is stimulating. When the traveler arrives at the summit of a mountain such as Pike's Peak, altitude 14,110 feet, he may feel unusually well and exhilarated, often showing a disposition to be talkative, unreasonable, or quarrelsome. His lips are blue, he is unusually sensitive to cold, feels light-headed, and may have a headache. As the day passes, in six or eight hours, lassitude is felt: the headache, which is frontal, gets worse; the appetite fails; there is likely to be nausea and vomiting; and frequently there is a sense of oppression in the chest and a rapid pulse. There is always depression, more or less muscular weakness, and sometimes complete prostration. The next morning the eyes are dull and heavy, temperature subnormal, the tongue furred, and the bowels disturbed. This condition may last a day or two, and if the patient remain quiet the attack is soon over. Strauch (88), having reviewed the mountain sickness experiences of early explorers, calls attention to the fact that this malady befalls some individuals at a lower, others at a higher altitude; but that for all there is a critical line beyond which escape is impossible. In some it may occur at 10,000 feet, while only a very few can venture to 19,000 feet without the experience.

Ravenhill (75) who had a large experience among the Andes Mountain mining camps at 15,400 feet describes, in addition, a cardiac and a nervous type of mountain sickness; the former is characterized by acute heart failure and the latter by persistent vertigo, trembling, and even convulsions.

THE RESPIRATION AT HIGH ALTITUDES.

The early observations on the influence of altitude on respiration dealt mostly with the rate, depth, and per minute volume of breathing and have shown that the amount of change varies with individuals (26), (36), (70), (104). Altitudes up to 15,000 feet either slightly increased or decreased the rate of breathing; the depth of breathing as a rule was increased although in some men the opposite resulted; and the per minute volume of breathing was found to be increased, but when corrections were made for temperature and pressure by reducing the volume to 0° C. and 760 millimeters the volume of breathing at 15,000 feet was from 10 to 78 per cent less than at low altitudes.

Altitude and other types of low oxygen studies have thrown much light on the method of control of respiration. To Haldane is due the credit of initiating the study which has given not only the facts but also very largely our present day interpretations. At low altitudes a close relationship exists between the alveolar tension of carbon dioxide and the per minute volume of breathing; the two vary proportionately, but the carbon dioxide tension remains rather constant. However, at high altitudes the opposite relationship obtains, the alveolar carbon dioxide is decreased while the breathing is increased. This difference is based upon blood changes. The alveolar air changes in carbon dioxide and oxygen can be used to determine just when and to what degree the respiration responds to altitude. Zuntz and coworkers (104) and Durig's (26) Monte-Rosa Expedition in 1906 determined, by indirect methods, that the alveolar carbon dioxide is lowered as the barometric pressure falls; but it required the more exact and direct method of Haldane and Priestley (47) to follow the changes in detail. The direct method was early applied by Boycott and Haldane (14) in a low pressure steel chamber, and later by Ward (98) on Monte Rosa, and by the Anglo-American Expedition (23) on Pikes Peak.

The members of the Anglo-American Expedition at 14,110 feet already showed a fall in the alveolar carbon dioxide when the first analysis was made in from 30 to 60 minutes after arrival on the summit. This indicates that the respiratory response began during the journey up the mountain. However, the process was then by no means completed. The average CO_2 tension upon arrival was 32.8 millimeters; this was followed by a gradual fall for from 3 to 19 days when it went to between 25.4 and 29.5 millimeters. In all cases the alveolar tension of oxygen was of course least the first day or so, ranging from 40.2 to 47.1 millimeters; and then gradually rose as the CO_2 tension fell, reaching finally from 54 to 56.4 millimeters. This rise in alveolar oxygen pressure is one of the important events of acclimatization. Had the sea level CO_2 tension of 40 millimeters been maintained at 14,110 feet, the alveolar oxygen pressure would have been only 36 millimeters. The new regulation gradually raised the alveolar oxygen pressure a little more than 16 millimeters above what it would otherwise have been.

A fall in the alveolar CO_2 tension indicates an increase in the per minute volume of breathing. The Anglo-American Expedition found that one individual breathed per minute in bed at sea level 7.7 liters; and when acclimated at 14,110 feet, 10.2 liters; when standing at rest at sea level 10.4 liters; and at 14,110 feet, 14.9 liters.

Miss Fitzgerald (32), (33), from a study of acclimated inhabitants of many altitudes found that the alveolar CO_2 pressure diminishes as altitude increases. She formulated the law that for every fall of 100 millimeters in the barometric pressure there is approximately a fall of 4.2 millimeters in the alveolar carbon dioxide pressure. This means that approximately a 15 per cent increase in the ventilation of the lungs occurs for each 5,000 feet increase in altitude.

During rest, in the acclimatized person, the breathing is ordinarily modified only in depth. During physical exertion the rate increases more rapidly than in the same exercise at sea level. Thus one subject when standing at sea level breathed 17 times per minute, on Pike's Peak 20 times; walking at the rate of 4 miles per hour at sea level 17.2, on Pikes Peak 29 times; and at the rate of 5 miles per hour at sea level 20, and on Pikes Peak 36 breaths per minute. The increase in the volume of breathing for the same conditions were: standing at rest at sea level 10.4, on Pike's Peak 14.9 liters; walking at 4 miles per hour at sea level 37.3, on Pike's Peak 57 liters; walking at 5 miles an hour at sea level 60.9, and on Pike's Peak 110.2 liters per minute. These figures make it clear that excessive hyperpnea is experienced on exertion during a sojourn at 14,000 feet, but this becomes less marked after the first day or two.

The consumption of oxygen during such exertions is approximately the same for each degree of effort at sea level and the high altitude. Most of the investigations show that metabolism is independent of variations in barometric pressure (23), (27), (28), (36), (53), (92), (104).

By means of experiments conducted in a low-pressure steel chamber and by low percentages of oxygen at normal atmospheric pressure, Lutz and Schneider (66) have attempted to simulate the rate of ascent of an aviator to 18,000 or 20,000 feet. The alveolar CO_2 pressure and the per minute volume of breathing were found to be changed at 656 millimeters barometric pressure (4,000 feet). Ellis (30) by the rebreathing method secured as early a response. It appears, then, that the respiratory response of increased breathing is stimulated almost at once by altitude during flying. The alveolar carbon dioxide and oxygen tensions fall progressively during an ascent to 20,000 feet, the carbon dioxide from an average of 39.7 to 30 millimeters and the oxygen from an average of 103.2 to 34.8 millimeters. The oxygen pressure in the blood as it leaves the lungs would average, according to Barcroft (6), 5 millimeters less than the alveolar oxygen pressure. So we have in the alveolar oxygen pressure, by referring to the normal dissociation curve, a measure of the degree of saturation of the arterial blood with oxygen and, therefore, of the degree of anoxemia.

In an assent of short duration, such as an airplane flight, if a high level be maintained for an hour or more there is a tendency for the alveolar carbon dioxide tension to rise somewhat and the per-minute volume of breathing to decrease toward normal. Ellis (30) and Lutz and Schneider (66) correlate these changes with the appearance of other compensations to low oxygen that are advantageous to the subject, while Haldane, Kellas, and Kennaway (49) attribute this falling off in the breathing to a washing out of preformed CO_2 from the blood by the increased breathing.

The after effects on the respiration of a stay at a high altitude of one or two hours are of short duration. Lutz and Schneider with low pressure chamber experiments found that, in a stay of from 30 to 90 minutes at a pressure corresponding to 15,000 feet, in four out of five subjects the alveolar air CO_2 was back to normal within 20 minutes after returning to 760 millimeters, while in only four out of nine cases was the return made in the same time after a stay at 18,000 feet. It has been a common observation among aviators that breathing is subnormal for awhile after landing. In that time the organism is making up the loss in CO_2 and recalling alkali into the blood. There is evidence that relatively permanent factors of adaptation soon begin to relieve the more temporary compensations. Thus Boycott and Haldane (14) report a case held 24 hours

at 545 millimeters in a low-pressure chamber in which the alveolar CO_2 pressure had scarcely returned to normal after two days. The persistence of the after-effects has been noted after residence on a mountain by Ward (98) and by the Anglo-American Expedition (23). The most conspicuous case was reported by Schneider (78) for a man who had lived six months on the summit of Pike's Peak. This man continued to show a hyperpnea for at least four weeks, in which time his alveolar CO_2 tension gradually rose from 27.1 to 37 millimeters. While the aviator breathes subnormally, the mountaineer ventilates his lungs excessively during the period of "after effect." The former has an alkalosis of the blood and the latter a high ratio of fixed acids to bases. The mountaineer very likely is slowly accumulating blood alkalies and increasing the blood content of volatile acids.

Periodic breathing is frequently observed among newcomers at very high altitudes. This was first observed by Mosso (70), and later studied by Douglas (21) and by the Anglo-American Expedition. It no doubt is caused by want of oxygen, in that it has been abolished by the administration of pure oxygen.

VITAL CAPACITY.

Authorities agree that a decrease in the vital capacity takes place with a lowered barometric pressure, but the explanations as to cause differ. Zuntz and coworkers (104) explain this change as being due to the expansion of intestinal gases. Durig (26) leans toward fatigue of the respiratory muscles as the true explanation. Fuchs (36) finds cause in an increase of muscle tone due to low temperatures. Durig and Zuntz (27) later accept in part this viewpoint. Experiments in low-pressure chambers give a similar reduction. Schneider (68) by this means has shown that the breathing of oxygen prevents a part of the decrease.

OXYGEN SECRETION BY THE LUNGS.

Opinion has been divided as to the means by which the passage of oxygen into the blood is effected at high altitudes. One group, the larger, has maintained that both at low and high altitudes the oxygen enters the blood solely by diffusion through the pulmonary epithelium; whereas the other group has maintained that diffusion alone can not account for the intake of oxygen, but that it is supplemented by an active secretion of oxygen by the pulmonary epithelium. The secretory theory has received its support from observations of the Anglo-American Pikes Peak Expedition. It is admitted that, if the oxygen pressure in the blood be higher than in the alveolar air, only the secretory theory will account for this difference. In order to measure the partial pressure of oxygen in the blood of men on Pikes Peak, Douglas, Haldane, Henderson, and Schneider (23) used the indirect method of Haldane and Smith (46), as modified by Douglas and Haldane (22), in which the administration of carbon monoxide and the law of mass action are employed to determine the partial pressure of oxygen. By this means they found the average excess of oxygen pressure in the arterial blood was 35.8 millimeters, the mean normal resting alveolar oxygen pressure 52.5, and the arterial pressure 88.3 millimeters. They also used the then known facts regarding diffusion of oxygen and found that alveolar oxygen pressure at that altitude would not deliver oxygen to the blood rapidly enough to supply the bodily needs, especially during exercise. To-day it appears that these results and conclusions were based on untrustworthy assumptions. Dr. Marie Krogh (60) in 1915 established a new diffusion-coefficient for the passage of oxygen through a membrane and showed that, if the figures were correct, it was possible for diffusion to account for the passage of a sufficient amount of oxygen to supply the body needs up to such altitudes as 24,000 feet. The theory so far as altitudes are concerned was from then on only supported by the indirect evidence that the oxygen pressure in the arterial blood was higher than in the alveolar air. More recently Barcroft, Cooke, Hartridge, and Parsons (9) drew blood directly from the radial artery of the wrist of a man who had lived 6 days under an oxygen pressure of 84 millimeters. By carefully controlled methods the oxygen pressure of the blood was determined by two direct methods of measurement—the blood-gas pump and the differential blood-gas apparatus. They conclude that "The arterial blood *in vivo* contained less oxygen both during rest and work than did samples of the same blood exposed to alveolar air *in vitro* at body temperature." So for the present it appears that the burden of proof for the theory of oxygen secretion by the lungs lies with its advocates.

THE BLOOD CHANGES.

The extensive literature on the blood is discordant, some maintaining that altitude is entirely devoid of effect and others insisting that extreme changes occur. This lack of agreement is most conspicuous regarding the changes in the number of red blood cells. A good review of the early literature is given by Bürker, Jooss, Moll, and Neumann (15). Their work emphasizes the necessity of employing experimental methods of a high degree of accuracy.

ERYTHROCYTES AND HEMOGLOBIN.

As early as 1878 Paul Bert (10) predicted that the blood of man and animals living at high elevations would be found to have a greater oxygen capacity than that of similar individuals at sea level. In 1882 (11) he showed that the blood obtained from several kinds of animals living at a high altitude in Bolivia had a greater oxygen capacity than that taken from animals at sea level. A little later, in 1890, Viault (95) reported an increase in the number of red corpuscles per cubic millimeter of blood in man and animals at an elevation of 14,400 feet in Peru; while Müntz (72) found that the blood of animals living at an altitude of 9,400 feet in the Pyrenees contained a larger percentage of iron than that of those at low levels.

While these early observations have from time to time been controverted, at the present time the evidence for an increase in the erythrocytes and hemoglobin is overhelming.

The relation between the increase in the number of erythrocytes and amount of hemoglobin has also been a subject of debate. Schaumann and Rosenqvist (77), Oliver (73), VanVoornveld (96), and Fuchs (35) found that the increase in red cells exceeded that of hemoglobin, while Eggers (29) and Dallwig, Kolls, and Loevenhart (20) report a much smaller increase in red cells than in hemoglobin. The Anglo-American Pikes Peak (23) Expedition in 1911

found the red corpuscles to increase in equal proportion with the hemoglobin, so that there was no alteration of the color index. Bürker (15) and collaborators at 6,150 feet found the erythrocytes to increase 4 to 11.5 per cent and the hemoglobin 7 to 10 per cent. Cohnheim (18) and Schneider and Havens (82) find the two changes run parallel. It is to be expected that as more exact methods of determining the hemoglobin come into use it will be shown that the color index is not changed with altitude.

If the increase in erythrocytes and hemoglobin prove to be parallel, then Miss Fitzgerald's (32) law may be accepted as a measure of these blood changes. She found that for every 100 millimeters fall in atmospheric pressure there is, among acclimated inhabitants, an average rise of about 10 per cent in hemoglobin and that this rise is approximately the same for men and women.

The aviator and balloonist may also experience blood compensations. Studies during a flight are difficult to make and subject to the criticism that the wind causes such rapid evaporation of the freshly drawn blood that an increased count may be attributed to its action. Gaule (39), Gemelli (40), and Culpepper (19) report increases in the erythrocytes and hemoglobin during flights; and the last two authorities hold that repeated ascents will give a permanent increase. They advance the opinion that cold is the main cause. A rapid increase in the absence of cold has been demonstrated by means of the low-pressure chamber and under low oxygen at normal atmospheric pressure by Gregg, Lutz, and Schneider (42). They and Haldane, Kellas, and Kennaway (49) fail to find a lasting effect from brief exposure to low-oxygen tensions.

RATE AND TIME OF CHANGE.

To determine the rate at which these blood changes take place during residence at a high altitude necessitates making allowance for the diurnal variations. Dreyer, Bazett, and Pierce (25) have shown that the daily variations in the per cent of hemoglobin in man and animals are large, changes of 10 per cent are more or less common, and may even reach as much as 30 per cent. The diurnal curve shows two maxima between 4 and 8 a. m. and p. m. and two minima between 10 and 1 o'clock night and day. If the literature on altitude blood changes be examined with this curve some of the disagreement between investigators can be accounted for.

The time required for the altitude blood changes to become evident appears to be determined by the rate and height of the ascent and the physical condition of the subject and, to some extent, by the amount of physical effort made. Gregg, Lutz, and Schneider (42) with the low-pressure chamber and low oxygen at normal atmospheric pressure observed that, when the oxygen tension was lowered at a rate comparable to ascending 1,000 feet per minute, to pressures corresponding to 15,000 to 18,000 feet, the erythrocytes and hemoglobin increased in 78 per cent of all men examined. In some of the men the increase began within 26 minutes and in the majority between 40 and 60 minutes.

The mountaineer, whether going afoot, by railway, or automobile, ascends more slowly than the aviator; consequently the blood changes appear much later. Douglas, Haldane, Henderson, and Schneider (23) observed in themselves, several hours after reaching the summit of Pikes Peak, a slight increase in hemoglobin that did not reach 3 per cent in any case. Work with animals has revealed an increase within a few hours (16), (20). Schneider and Havens (82) had under observation healthy young men who ascended passively by railway and showed no response during the first 7 hours at an altitude of 14,110 feet. The usual response during residence at a high altitude consists of a rapid increase in the number of erythrocytes and percentage of hemoglobin during the first two to four days, followed by a more gradual increase that requires several weeks and even months to establish equilibrium. Individual differences are always observed when a group of men is considered, as in the Anglo-American and the Bürker expeditions. A splendid set of observations that gives the typical curve is that of Richards (74) on himself, at 15,000 feet, in Bolivia. In five days his hemoglobin increased from an average of 101 to 129 per cent on the Gower–Haldane scale, and then rose very gradually for two and one-half months to 146. A residence of a few days to a week at the high altitude is not sufficient time for the changes to be completed. Schneider and Havens (82) observed two men who failed to respond in four days and others in whom the first changes were delayed one and two days. The men who were tardy in making these blood changes were fatigued by ascending on foot or were not in the pink of condition. The Anglo-American Pikes Peak expedition noted a distinctly low hemoglobin in three of the party the day following a fatiguing climb.

THEORIES ON THE MECHANISM OF ADJUSTMENT.

Among the theories advanced to account for the increase in the erythrocytes and hemoglobin are (*a*) an increased concentration of the blood; (*b*) increased hematopoietic activity of the bone marrow; (*c*) the existence of a reserve or dormant supply of ertyhrocytes; (*d*) a lengthening of the life of the erythrocytes (for which there has been no experimental evidence); and (*e*) an unequal distribution of the red corpuscles.

Grawitz (41) early maintained that as a result of increased evaporation of water from the body the blood becomes more concentrated at high altitudes. Weiss (101) was unable to detect any alteration in the amount of hemoglobin per kilo body weight in animals at 4,000 feet, even though the number of erythrocytes per cubic millimeter was increased. Jaquet (57), on the other hand, found in animals kept under a barometric pressure of 640 millimeters of Hg. (5,000 feet) that not only the percentage of the hemoglobin but also the total mass of hemoglobin increased, while the volume of blood remained practically unaltered. Abderhalden (1), working with animals at 6,100 feet, concluded that the amount of hemoglobin per animal was not altered, although the amount per kilo body weight as well as the percentage value of the hemoglobin and red corpuscles rose. The weight of his animals was uniformly less at the high altitude. He took this to indicate a concentration of the blood without overproduction. Dreyer and Walker (24) believe that the change in blood volume is proportional to the area of the body surface. They recalculated Abderhalden's data and found that while the animals showed a diminished blood volume, yet the total amount of hemoglobin indicated a new formation; but they concluded that in animals examined during the first day or two after ascent the whole change was due to a

diminution in the blood volume. Douglas, Haldane, Henderson, and Schneider, by the carbon monoxide method of Haldane and Smith (46), determined the total amount of hemoglobin and the blood volume of four men during a residence of five weeks on Pikes Peak. They are of the opinion that three of their subjects had a diminished blood volume during the first days, but that afterwards there was a large increase in the total amount of hemoglobin and a return to, or even a slight increase above, the normal volume.

Other evidence of increased activity of the hematopoietic tissue has been forthcoming. Thus Zuntz, Loewy, Müller, and Caspari (104), by a histological study of the bone marrow of dogs at sea level and at a high altitude, showed a decrease in fat cells and an increase in the blood-forming elements in the animals acclimated to the high altitude. Dallwig, Kolls, and Loevenhart (20) found an extension of the red marrow in animals under low oxygen, and a large increase of hemoglobin per kilo body weight. Laquer (63), working with dogs, found that if they were deprived of hemoglobin by a hemorrhage of half their blood supply, at sea level 27 days and on Monte Rosa 16 days were required to regenerate the hemoglobin. Schneider (78) proved there had been overproduction of red corpuscles and hemoglobin by determining the changes after descent in a man who had lived 6 months at an altitude of 14,000 feet. In the course of 10 weeks the total oxygen capacity of the blood decreased about 12 per cent.

Schneider and Havens (82), from observations on the effects of abdominal massage and muscular exertion, concluded that a part of the first increase in red corpuscles and hemoglobin occurring with residence at a high altitude was brought about by the passage into the general circulation of a large number of red corpuscles that ordinarily are stored away. Their reasons were as follows: At low altitudes abdominal massage and physical exertion increase the number of erythrocytes and percentage of hemoglobin in the peripheral capillaries; at high altitudes, before the blood changes of acclimatization have appeared, these still raise the content of hemoglobin and red corpuscle; but after men are partially or wholly acclimatized abdominal massage and exercise lower instead of increase their content. Recent work on the regulation of the volume and concentration of the blood has not favored this explanation. Scott (86) was unable to find masses of corpuscles stored away anywhere in the body and believes that the capillary blood is the same as that in the large vessels. Scott, Herrman, and Snell (87) found an increase of the water content of the muscles during contraction and concomitantly with this an increased hemoglobin content and blood count. This passage of water out of the blood was associated with a rise in blood pressure. Lamson (64) also was unable to find a reservoir of red corpuscles of sufficient magnitude to appreciably influence the red count. He finds that all conditions of acute polycythemia in which there has not been sufficient time for red cell production are due to concentration of the blood by fluid loss, and that this loss from the circulation occurs through the liver lymphatics. While these more recent studies throw doubt on the explanation offered by Schneider and Havens, they do not account for the fact that after acclimatization abdominal massage and physical exertion not only failed to cause the usual concentration of the blood, but actually caused a decrease in the content of hemoglobin and the red cell count.

The mechanism by means of which the blood is concentrated has not been carefully considered with respect to altitude and low oxygen. That it is not chiefly the result of evaporation of water from the body as suggested by Grawitz is evident from the observation of Dallwig, Kolls, and Loevenhart and of Gregg, Lutz, and Schneider, in which men and animals were held under such conditions that perspiration and evaporation were normal or subnormal; furthermore Gregg, Lutz, and Schneider obtained concentration within 15 to 20 minutes without any noticeable increase in the activity of sweat glands. Against the theory that it is chiefly due to an increased activity of the kidneys, as suggested by Birley (12) from observations on aviators, Gregg, Lutz, and Schneider urge that the time in which concentration occurs, 15 or 20 minutes as seen in some aviators, is too short and the volume of urine eliminated too small. A study of the weight of subjects before and after experiment proves conclusively that the concentration can not be due to a loss of water from the body. That it is not associated with the blood pressure is evident from numerous mountain, low-pressure chamber, and rebreathing experiments in which the arterial pressures have not increased, but in some instances have decreased as the blood concentrated. The work of Bogert, Underhill, and Mendel (13) and Scott, Herrman, and Snell (87) show that in the regulation of blood volume the tissues act as the reservoir for excess fluid. Furthermore, as shown by Smith and Mendel (90), the excess of fluid may leave the blood as an exudate into the serous cavities or be excreted into the intestine and stomach.

The theory that the blood changes of altitude are due to an alteration in the distribution of the erythrocytes has had its chief support from Foa (34), who found that the ear veins of rabbits contained more red cells than the blood from an artery; and from Campbell and Hoagland (16), who found the blood from the mesenteries poorer in erythrocytes than that from the ear. Dallwig, Kolls, and Loevenhart (20) later examined blood from the marginal ear vein and the carotid artery and heart and found the counts were the same within the limits of experimental error.

Undoubtedly the increase in hemoglobin observed, during short exposures to and during the early days at high altitudes, is largely or wholly due to a loss of fluid from the blood; while the permanent condition of acclimatization is the result of a new formation of red cells which finally restores the blood volume to normal.

Reasoning from the fact that his own erythrocytes did not increase during a short visit to Leadville and Pikes Peak at a time when his red count was abnormally high at sea level, Sundstroem (93) concludes that health in high altitudes is compatible with numbers of red cells that are normal for low elevations. The opinion is not in accord with some able clinicians. Sewall (76) considers anemia a dominant disorder at altitudes of 5,000 and 6,000 feet. He finds that failure to react normally to the altitude leaves the body in a mild grade of altitude anemia that originates or accelerates many functional disorders. Moleen (69) also finds much of the so-called altitude nervousness due to the failure of the hematopolitic response and that, if by therapeutic or other means the

blood-forming mechanism can be stimulated into activity, individuals find no difficulty in living tranquil lives at high altitudes.

Variation in the size of the erythrocytes has been considered. Koeppe (59) found a decrease while Schauman and Rosenqvist (77) report a progressive increase in the diameter at high elevations. Sundstroem (92), (93) observed that in the same person on different occasions there may be either an increase or decrease in the diameter and suggests that these alterations may be caused by, or correlated with, changes in the acid-base equilibrium of the blood.

Numerous attempts have been made to find nucleated red corpuscles but many have been futile. Schauman and Rosenqvist in experiments on animals found an increase of normoblasts and free nuclei. Gaule (39) from balloon ascensions gives doubtful descriptions of nucleated red cells and Sundstroem after much searching of his own blood found two characteristic normoblasts and a few free nuclei. Dallwig, Kolls, and Loevenhart (20), working with animals kept under a low percentage of oxygen, showed that the number of basophilic erythrocytes was increased and that many of these were abnormally large. Such cells are indicative of excessive activity of the hematopoietic tissue.

LEUCOCYTES AND PLATELETS.

The number of white corpuscles is approximately the same at all altitudes (91), (92), but the differential count reveals a difference in the kinds of leucocytes. The outstanding feature is an increase in the large lymphocytes. The number of polymorphonuclear cells diminishes in exact proportion in which the mononuclear cells increase (91), (92), (99).

Comparatively little work has been done in connection with the blood platelets. Kemp (58) in 1903 found a tremendous increase at 14,000 feet. Webb, Gilbert, and Havens (100) found that the platelet count at sea level as obtained from an average of counts made on 100 college students was 302,000, and for 100 men at 6,000 feet was 340,000 per c. mm. No reason is known for this increase.

THE HEMATO-RESPIRATORY FUNCTIONS AT HIGH ALTITUDES.

The whole problem of respiration at high altitudes is very closely linked with the control of the chemical reaction of the blood and therefore with the explanation of acidosis. Our interest centers about the balance of acids and alkalies because the absorption and unloading of oxygen by the blood is altered by variations in these. Carbon dioxide, by virtue of its acidic character, affects not only the respiratory center but also the dissociation of oxyhemoglobin; an increase in the partial pressure of carbon dioxide augments the dissociation, while a decrease causes the hemoglobin to hold more tightly to its oxygen.

It was early noted that the volume of air breathed is increased at high altitudes, while the alveolar carbon dioxide pressure is lower than at sea level. To account for this increase in breathing Zuntz and associates (104) and Haldane and collaborators (14), (48), (98) developed a theory that still persists, to a degree, among physiologists today; namely, that a deficiency of oxygen produces acids that are added to the blood. Boycott and Haldane (14) believed that the hyperpnea observed under want of oxygen is due to the formation of lactic or other acid substances and that these have the same influence as carbon dioxide on the respiratory center, so that less carbon dioxide is required to excite the center. That lactic acid does not accumulate in the blood, at least at moderately high altitudes, was proven by Barcroft, Camis, Mathison, Roberts, and Ryffel (7), (8) in their expedition to Mount Rosa.

Studies of the dissociation curve of the blood by Barcroft (7) and the Anglo-American Pikes Peak Expedition (23) have shown that, in the acclimated individual, the affinity of hemoglobin for oxygen is the same as at sea level, if the blood be exposed to a carbon dioxide pressure characteristic for the alveolar pressure of the altitude. This indicates that the carbon dioxide has been displaced by something which produces an equal effect on the affinity of hemoglobin for oxygen. If the blood of an altitude acclimated person be exposed to 40 millimeters of carbon dioxide, the average alveolar carbon dioxide at sea level, the dissociation curve is displaced to the right, thus proving there has been an increase in acid radicals or a decrease in the bases of the blood. To account for these changes Douglas, Haldane, Henderson, and Schneider suggested the theory that the adaptive regulation of the blood alkalinity is accomplished by a slight and gradual alteration in the exciting threshold of alkalinity for the kidneys, whereby they would slowly reduce the alkalinity of the blood and restore the acid-base relationship to that characteristic of acclimated persons. The stimulus for the slight alteration was assumed to be the presence of abnormal quantities of metabolites in the blood which had escaped oxidation in the lungs. This theory has recently been modified by Haldane (45) in view of more extended observations.

Y. Henderson and Haggard (44), (54) have used the carbon dioxide dissociation curve of the blood to show the amount of alkali in use in the blood. They find, with oxygen deficiency, that augmented breathing begins before a reduction of the blood alkali occurs, and that there is not a lowering of the blood alkali before or coincident with the increase in breathing, as was formerly taught. They find the hemato-respiratory events of acclimatization occur in the following order: 1, a lowering of the oxygen tension of the inspired air; 2, a stimulation of the respiratory center or, as they state it, an increased production of respiratory x; 3, excessive respiration and a blowing off of carbon dioxide; 4, a decrease in the ratio of H_2CO_3: $NaHCO_3$, which means a lowering of the hydrogen ions, an alkalosis of the blood instead of the acidosis of earlier theories; and 5, a compensatory disappearance of alkali from the blood. In complete acclimatization to any altitude the volume of air breathed is in inverse proportion to the amount of alkali in the arterial blood. Unquestionably the oxygen tensions in the lungs and arterial blood give the condition to which the organism adjusts its respiratory activity.

Haldane (45) explains these hemato-respiratory changes of acclimatization as follows: The hydrogen ion concentration of the blood is regulated with great delicacy by the respiration on the one hand and the kidneys and the liver on the other, the respiration doing the rough and immediate work by increasing or decreasing the elimination of carbon dioxide, and the kidneys the finer and slower work by adjusting fixed alkalies and acids. Oxygen want serves as an additional stimulus to the respiratory center, causing

an increased amount of carbon dioxide to be washed out of the arterial blood. This loss of carbon dioxide makes the blood abnormally alkaline and causes the kidneys and liver to slowly redress the balance, the kidneys by excreting the excess of alkali and the liver by suppressing the accumulation of free ammonia.

The evidence in favor of the latest theory is the work of a number of laboratories. That the respiratory center is directly stimulated by oxygen deficiency is indicated by experiments of Gasser and Loevenhart (38) on animals and Lutz and Schneider (66) on men, in which they find that the hyperpnea may be excited by want of oxygen within 4 to 35 seconds, average about 14.5 seconds; a time too brief to make it probable that the stimulation is due to the accumulation of metabolites in the blood or the respiratory center. Haldane, Kellas, and Kennaway (49) also conclude that oxygen deficiency *per se* can act as a stimulus to the respiratory center.

That there occurs increased breathing and a blowing off of carbon dioxide is clear from the alveolar air studies cited under our discussion of respiration. Theoretically the alveolar carbon dioxide is proportional to the carbon dioxide content of the blood. In addition direct measurements of the carbon dioxide content by Paul Bert (10) and Mosso and Marro (71) on dogs and by Sundstroem (92), by Van Slyke's method on himself, confirm the opinion that low oxygen tensions cause a loss of carbon dioxide from the blood.

In 1918, by simultaneous determination of carbon dioxide content and carbon dioxide capacity (which is a measure of the alkalinity) of the blood, Y. Henderson and Haggard (55) have shown that a decrease of the former is followed by a decrease in the latter, but that a lagging behind of the carbon dioxide capacity may occur. In a later paper they cite experiments made upon men by this method by Lutz and Schneider (44), in which the blood alkali during periods from 60 to 90 minutes of oxygen deficiency was not reduced, even though the carbon dioxide was reduced and the normal ratio H_2CO_3: $NaHCO_3$ was changed in the direction of a temporary alkalosis. Sundstroem (92), during the first two days of a sojourn at 14,110 feet, found the urinary excretion of base much less than later, while the hydrogen ion determination of the blood indicated an alkalosis.

That later the kidneys and liver restore the hydrogen ion content of the blood has been proven in several ways. Hasselbalch and Lindhard (53) found that the H-ions of the urine were reduced for several days and returned to normal only after acclimatization was established, and that the excretion of ammonia was also relatively decreased and continued somewhat low even after acclimatization. This latter condition Haldane (49) considers an evidence of a slight continuous alkalosis. By carefully constructing balance sheets of all the acid and basic elements in the food, feces, and urine, and thus obtaining the total acid-base balance of the body at low and high altitudes, Sundstroem (92) at high altitudes found an increased output of base which consisted largely of fixed alkalies. He also obtained a decrease in the ammonia output which he explained as a corollary to the increased elimination of fixed alkalies. In this connection it should be noted that Macleod (67) has suggested that an excess of lactic acid in anoxemia may perform the function of neutralizing the relatively increased base. Sundstroem, however, found that excretion of lactic acid did not increase. Haldane, Kellas, and Kennaway (49) have shown that the titrable acids, as well as the ammonia, of the urine are much reduced during exposure to oxygen deficiency. These observations clearly indicate that it is the function of the liver and kidneys to restore the H-ion content of the blood resulting from the loss of carbon dioxide, and thus to give the final hemato-respiratory equilibrium of acclimatization. It is also evident that the total alkalinity, the alkaline reserve, is reduced in inhabitants of high altitudes.

There is a lack of agreement as to what maintains the greater ventilation of the lungs and the low alveolar carbon dioxide after acclimatization. Barcroft (7) found that at any altitude, the acidosis and diminution of carbon dioxide so nearly balance one another that the reaction of the blood remains practically constant; and yet he has been able to show by a statistical study that there was a slight increase in acid over the sea-level amount, and this he considered sufficient to give the respiratory center the slight stimulation which would account for the altitude increase in lung ventilation. Sundstroem, by an indicator method, finds a slight acidosis of the blood after successful acclimatization that lends support to Barcroft's position.

Hasselbalch and Lindhard (53) give a different interpretation. They find in acclimatization that the H-ion concentration of the blood is the same at all altitudes, and hold that the primary change is in the respiratory center, which becomes abnormally sensitive to the H-ions, resulting in increased breathing.

Haldane (45) is of the opinion that while after acclimatization the H-ions are again probably nearly the same as at sea level, yet the restoration is never quite complete; so in the end there continues a slight alkalosis which gives evidence of a continued though slight oxygen want, and it is this that still permits action of diminished oxygen on the respiratory center. Henderson (44) believes that it is a low oxygen to alkali ratio that tends to stimulate respiration. Or rather, it is the low oxygen—alkali ratio—which produces the respiratory x, that stimulates the respiratory center. He declares that it is not enough to say that oxygen deficiency is itself a stimulus or that it governs the excitability of the respiratory center for carbon dioxide, as these leave the question of how it does this unanswered. He therefore postulates an unknown substance, labeled respiratory x, that is formed by the action of the oxygen—alkali ratio.

During the early stages of adjustment to the low oxygen tension of high altitudes, the condition in the blood is favorable to a serious oxygen want. The loss of carbon dioxide from the blood should mean an increased affinity for oxygen. When the blood is in the lungs this would lead to a better absorption of oxygen than normally. However, when the blood is in the systemic capillaries the opposite is the case, and this same affinity then prevents as free a passage of oxygen outward from the blood as normally would occur at lower altitudes. Therefore, until the liver and kidneys overcome the alkalosis of the blood, the tissues of the organism suffer an oxygen want to a greater degree than they will later. The restoration of the normal hydrogen-ion content of the blood, in that it restores the oxyhemoglobin dissociation curve to about its sea-level value, must be regarded as an important factor in acclimatization.

MOUNTAIN SICKNESS.

The aviator, as has been previously pointed out, does not suffer from mountain sickness but simply from oxygen want. The degree appears to be determined chiefly by two factors, namely, the partial pressure of oxygen in the alveolar air of the lungs and blood, and by the degree of alkalosis of the blood. The latter as shown above affects the oxyhemoglobin dissociation by preventing the normal dissociation of oxygen and thus decreases the amount that passes to the tissues. The effects, as indicated by the recorded symptoms, appear to be chiefly caused by want of oxygen in the brain.

A complete explanation of mountain sickness has not yet been given. Without doubt it is chiefly due to anoxemia, so that such of the older theories as attribute it to mechanical causes and to the absence of carbon dioxide may be here neglected. Barcroft (7) believes that mountain sickness is caused by want of oxygen on the brain itself, but that the vomiting center is stimulated by the lack of acid in the blood. He points out that the symptoms of mountain sickness resemble those of a hemorrhage. As a preventive, he urges that acids be courted by physical exercise.

Y. Henderson and Haggard (44) believe that their postulated respiratory x may cause the symptoms of mountain sickness, in that it at first acts very much like ethyl ether in the excitement stage; while its later effects resemble the disagreeable manifestations of alcoholic intoxication.

Haldane, Kellas, and Kennaway are unable to say to what extent mountain sickness is due to anoxemia or to the secondary diminution of the H-ions of the blood (alkalosis), but they believe the two causes are closely bound up together. Sundstroem states that it is possible that mountain sickness can be directly explained as a failure of the kidneys to respond sufficiently quickly to the excess of bases in the blood. He found an alkalosis of the blood during his attack of mountain sickness, and a normal H-ion concentration in the afternoon of the same day, when the symptoms of mountain sickness had entirely disappeared. Haldane, Kellas, and Kennaway are of the opinion that good toleration of high altitudes is dependent upon the ability to quickly eliminate the excess of blood alkalies. The observations of Mosso (71) and of Hasselbalch and Lindhard (53) that the symptoms of mountain sickness were reduced by the inhalation of proper dilutions of carbon dioxide, and Barcroft's suggestion of courting acid, find a satisfactory explanation in the theory that alkalosis is at least a secondary cause of the symptoms of mountain sickness.

THE CIRCULATORY MECHANISM AT HIGH ALTITUDES.

THE HEART RATE.

The response of the heart to oxygen deficiency gives a good illustration of the fact that the behavior depends upon the suddenness and the extent of the changes in oxygen. Lutz and Schneider (66) by having men inspire nitrogen, obtained an acceleration of the heart in from 5 to 55 seconds, in 66 per cent of all cases within 15 seconds or less. In a low pressure chamber, in which the barometric pressure was lowered at a rate corresponding to an ascent of 1,000 feet a minute, 26 per cent of all cases showed an increase at tensions of oxygen equivalent to an altitude of 4,000 feet or less. In airplane flights the psychic influence of the excitement of taking off usually obscures the beginning of the low oxygen effect, but Hodgson (56) has recorded several flights to 16,000 feet in which the typical low oxygen action is well illustrated. The experiments of Lutz and Schneider and the statistical study of Schneider and Truesdell (85) show that the heart rate slowly and gradually increases until the oxygen tension is about that of 14,000 feet, and from there on the increase is by much greater increments for each thousand feet of ascent. The increase averaged 15 beats at 15,000 feet and 20 at 18,000 feet.

Schneider (79), Lutz and Schneider (66) and Haldane, Kellas, and Kennaway (49) observed that, if a constant level of low oxygen be maintained for an hour or more, the rate in may cases again retards, although in some there is a continued augmentation during the entire time of maintained level.

In the slow ascent of mountains which is followed by a sojourn of weeks or months the story is different. The early literature has been reviewed by Durig and Kolmer (26) and Schneider and Sisco (83). If the ascent be made passively by railway to 14,000 feet there is, as a rule, no acceleration during the ascent. What happens later appears to depend on the physical condition of the subject. If he compensate well to the altitude, his pulse rate, at rest, will not show an increase for some hours; but by the next morning the rate, while in bed, will be slightly accelerated and continue to show a further increase each morning for from three to five days. In those less tolerant to altitude the heart accelerates as the attack of mountain sickness comes on, so the early morning rate may reach its maximum by the first morning. As the attack passes off the heart retards. In men who climb the mountain on foot or on a burro or horse, the fatigue of the climb causes the pulse rate to resemble that in mountain sickness. The greatest augmentation occurs in men physically weak. The daily variations in pulse rate show the same proportionate increase as the early morning rate when compared with similar conditions at lower altitudes. While a number of authors have thought the pulse extraordinarily labile at high altitudes, Schneider, Sisco and Cheley (84) did not find it necessarily so. The heart works at an increased rate in all postures at high altitudes, with about the same differences as at the low altitude. The amount of increase, of course, differs with individuals; some show, at 14,000 feet, an augmentation of only a few beats, while others increase 10 or more over the low altitude rate.

During a prolonged sojourn at a high altitude the heart rate may show a gradual daily increase for about a week or two, but as other adaptive changes reach their maximum efficiency there is a tendency to return toward the low altitude rate (23). In only rare cases does it completely return to the low altitude normal.

The "after effects" of a visit to a high altitude differ from those observed for respiration. After an exposure to oxygen deficiency for an hour or so the heart returns at once to its normal rate, but if the stay has been long enough for the permanent changes of acclimatization then the return to a low altitude may be followed by a subnormal rate. Durig and Kolmer (26), Schneider (78) and others (52), (92) have found a subnormal period that

lasts many days. All observers agree that up to altitudes of 8,000 or 9,500 feet the acclimatized inhabitants do not show an altitude augmentation in heart rate.

THE ARTERIAL PRESSURES.

The circulatory responses to oxygen deficiency as experienced during the short exposures in aviation have been the subject of a number of papers from Medical Research Laboratory of the Air Service of the Army (79), (66), (43), (64), (85). In a rapid ascent to 15,000 or 20,000 feet, if the psychic factor be not active, the systolic pressure in a good compensation remains unchanged or shows a slight gradual rise of not more than 10 or 15 millimeters. The diastolic pressure is also maintained to oxygen tensions corresponding to 15,000 feet and thereafter, as higher altitudes are attained, slowly decreases by about 8 to 10 millimeters. If the compensations to the low oxygen be inadequate the aviator is liable to develop a fainting circulatory reaction of which a rapid fall in the systolic and diastolic pressures gives evidence of the oncoming syncope. The various types of circulatory reaction have been described in detail by Schneider and Truesdell (85).

The arterial blood pressures of people living in the mountains have been made a frequent subject of study. The early literature has been reviewed by Schneider and Hedblom (81) and Durig and Kolmer (26). The conclusions of the Anglo-American Pikes Peak Expedition (23) and of Schneider and Sisco (83), who have examined a goodly number of men, are that the altitude effects in those who ascend the mountain passively are so slight that they fall for the most part within the errors of observation. In the majority of healthy men at 14,110 feet the arterial pressures were normal for them; in some there occurred a slight fall and in a few a slight rise. However, during an attack of mountain sickness and in some cases during the first days of inadequate compensation both the systolic and diastolic pressures are above normal.

VENOUS AND CAPILLARY PRESSURES.

These pressures have not received much attention in anoxemia. Under the acute conditions of rebreathing and low-pressure chamber experiments of from 25 to 45 minutes' duration, the low oxygen reduced the venous pressure (80). On Pikes Peak, Schneider and Sisco found a lower venous pressure than at low altitudes. A few capillary pressure determinations with Lombard's device indicated that this pressure was slightly lower on Pikes Peak.

VOLUME OF BLOOD FLOW.

This subject has been difficult to approach because of the lack of a satisfactory direct method of determining the per minute output of the heart. The Anglo-American Pikes Peak Expedition concluded, from observations by means of a recoil board and from the pulse pressure, that the volume of the heart strokes continued practically the same on Pikes Peak as under ordinary barometric pressure. In one man, however, the heart stroke appeared to be somewhat diminished. The volume of the blood stream per minute in one subject was decidedly decreased in another unchanged, and in two others somewhat increased. Schneider and Sisco's records show that the pulse pressure averages slightly less on Pikes Peak, but that with two exceptions the difference is too small (2 millimeters) to be significant. They believe that their recoil board records, along with those of pulse pressure, indicate that in four men the output per heart stroke was the same at both altitudes, but in another was reduced at the high altitude. Using Stewart's method of measuring the amount of blood flow through the hand, by determining the amount of heat given off in a water calorimeter, they found the circulation rate through the hands was for six subjects from 30 to 76 per cent greater on Pikes Peak. These observations, supplemented by those of the recoil board and pulse pressure and the fact that the pulse rate had augmented, led them to conclude that the circulation rate as a whole was more rapid. Bainbridge (5) has pointed out that this increase in blood flow through the hands may be due to a dilatation of the limb vessels counterbalanced by vasoconstriction elsewhere, presumably in the splanchnic area.

Hasselbalch and Lindhard (53), in six experiments in a low-pressure chamber, at a barometric pressure somewhat under 12,000 feet, using a respiratory nitrous oxide method developed by Krogh and Lindhard, found a slight increase in the output of the heart in three of the tests. The fact that this increase was slight and that the flow was unaltered in the other experimenets led them to conclude that the output of the heart is not increased at high altitudes during rest.

Kuhn (61), using the respiratory method of Plesch at an altitude of 11,000 feet, found that the output per heart stroke was decreased in two, unchanged in one, and increased in the fourth man; while the per minute volume output of the heart was somewhat augmented in each subject (3.2, 5.8, 8.3, and 28.1 per cent).

Lutz and Schneider (66) find, in low pressure chamber experiments, indications of an increased blood flow in the augmentation in the rate of heart and in changes in the arterial pressures, which result in an increase in the pulse pressure. They also find that, when a constant level of oxygen is maintained, the heart rate may diminish and the pulse pressure again decrease. The interplay of the various circulatory factors throughout their experiments seems to support the theory of an increased blood flow during anoxemia.

That the volume of blood passing through the lungs during acute anoxemia, in an anesthetized cat, was the same as under ordinary atmospheric air has recently been demonstrated by Doi (105), by the use of a method in which the oxygen consumption per minute and the oxygen content of arterial and venous blood were determined. From the minute volume thus obtained he calculated that the output of each heart beat had decreased. Doi's findings are by means of a more direct method than others reported above and make it appear that the acceleration of the heart in anoxemia is a symptom of distress and not of compensation. This problem of the volume of the blood stream from the heart needs further study by these more direct methods under more natural conditions than obtain in the use of anesthetics. To the writer it does not seem likely that the acceleration of the heart which appears at the same time as the respiratory changes, in acute anoxemia, is merely a distress symptom.

EXERCISE.

Physical exertion makes greater demands on the heart and blood vessels at very high than low altitudes. Just at what altitude this begins has not been investigated. Schneider, Cheley, and Sisco (84) found that the arterial pressures were higher after a given form of work at the high than at the low altitude and that the influence of lowered barometric pressure was the more pronounced the more vigorous the exertion. The increased reaction to exercise was most conspicuous during the first days of residence. While the effects were lessened by acclimatization for moderate exertion, they did not show improvement in strenuous exercise. The systolic pressure after short quick runs was as high as during a maximum lift of weights. Further evidence of greater exercise demand on the heart was that the delay in the return to normal was as prolonged as after exhaustive exercises. In physically-fit men the influence of altitude in exercise was less.

Clinicians have found that as a rule the danger to the heart in high altitudes is overstrain from exercise and is not specifically due to altitude. Schrumpt (85) finds that up to 7,000 feet pathological blood pressures are improved. Zederbaum (103), Wyss (102), and others point out a fear of altitude among the laity and even medical men that is unwarranted, and show that altitudes up to 6,000 or 7,000 feet benefit many forms of heart disease.

Accepting then, for the present, only such factors as have been clearly demonstrated to serve in the compensation to anoxemia, we may rank them as follows: 1, increased respiration; 2, chemical alterations in the blood; and 3, increased hemoglobin. The respiratory change ranks first because by this means the partial pressure of the oxygen in the lungs is raised above what it would normally be at the altitude. This favors not only the absorption of oxygen in the lungs, but also, after acclimatization, the passage of oxygen from the blood to the tissues. Since the alkalosis resulting from augmented breathing interferes with the passage of oxygen from the blood to the tissues, it can not be questioned but that the restoration of the normal H-ion content, by the elimination of the excess of alkali, constitutes a compensatory process of almost if not equal importance with the increase in breathing. The advantage gained by the increase in hemoglobin is not so obvious. Barcroft (6) finds the increase of but little value, since even if it be sufficient to restore to normal the actual quantity of oxygen in 1 cubic centimeter of blood then, because of the decrease in oxygen pressure, the rate of dissociation will be so slow that it will not allow the oxygen to pass to the tissues in anywhere near the same proportions. Haldane (49) considers the advantage of the increase in hemoglobin due to the fact that the partial pressure of oxygen in the blood of the systemic capillaries is prevented from falling as low as it otherwise would.

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AVIATION MEDICINE.

AN OUTLINE OF THE PROGRESS IN RESEARCH AND TEACHING OF THIS SUBJECT IN THE UNITED STATES DURING THE CALENDAR YEAR 1921.

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During the past year progress in aviation medicine has been made in this country almost entirely by the personnel of the Medical Research Laboratory and School for Flight Surgeons and those formerly connected with it. In summarizing this subject it will be simpler, therefore, to take up the work of the various departments of the Medical Research Laboratory and School for Flight Surgeons and outline the publications issued and the research accomplished at that institution. In a paper of this sort it will be possible to give only a brief summary of the most recent articles and the recent research, and in the case of articles republished this year which have been published in previous years and which have been reviewed in other places, to refer only to the titles for the sake of completeness of bibliography. It will be convenient to consider this work under the following heads:

I. Research and publications:
   1. Aviation physiology.
   2. Aviation medicine.
   3. Neuro-psychiatry.
   4. Ophthalmology and otology.
   5. Aviation psychology.
   6. Miscellaneous.

II. Schools of instruction:
   1. Instruction for flight surgeons.
   2. Instruction for enlisted men.
   3. Library.

III. Routine work:
   1. Physical examinations.
   2. Branch laboratories.
   3. X-ray and photography.
   4. Personnel: (*a*) Officer; (*b*) Civilian.

IV. The future of aviation medicine.

1. RESEARCH AND PUBLICATIONS.

1. Aviation Physiology.

During the year there has appeared in various medical, scientific, and other journals a number of papers that embody the results of researches conducted by the Department of Aviation Physiology in the Medical Research Laboratory and School for Flight Surgeons. The titles of these papers, with the place and time of publication, were as follows:

"A Record of Experience with Certain Physical Efficiency and Low Oxygen Tests," by Edward C. Schneider. American Journal of the Medical Sciences, March, 1921, volume 161, pages 395–407.

"The Application of Certain Physical Efficiency Tests," by Verner T. Scott, Captain, M. C. The Journal of the American Medical Association, March 12, 1921, volume 76, pages 705–707.

"Pulse Rate and Blood-Pressure Responses of Men to Passive Postural Changes," by Max M. Ellis. American Journal of the Medical Sciences, April, 1921, volume 161, pages 568–578.

"A Study of Low Oxygen Effects during Rebreathing," by Edward C. Schneider and Dorothy Truesdell. American Journal of Psysiology, March, 1921, volume 55, pages 223–257. This subject was also published with additional data and discussion in the Air Medical Service Information Circular, July 15, 1921, volume 3, pages 6–25.

A paper that was first published in 1920 in the Journal of the American Medical Association, and that was widely reviewed in this country and abroad, was republished, on the request of the editors, in Mind and Body, March 1921, volume 27, pages 449–456. The title was "A Cardiovascular Rating as a Measure of Physical Fatigue and Efficiency," by Edward C. Schneider. The same paper with the exception of the introductory and historical paragraphs was also reprinted in the Journal of Industrial Hygiene.

All of the above-mentioned articles were reviewed in the report of the Medical Research Laboratory and School for Flight Surgeons for 1920. In addition to these papers two more have been published. One of these was "A Study of the Influence of Various Circulatory Conditions on the Reaction to the Low Oxygen of Rebreathing," by Edward C. Schneider and Dorothy Truesdell, American Journal of Physiology, June, 1921, volume 56, pages 241–248. The same material with the addition of a larger amount of statistical data was discussed under the same title in Air Medical Service Information Circular, July 15, 1921, volume 3, pages 122–133.

In this research 10 special groups were selected from 2,000 cases for a study of the influence of various circulatory factors on the power of compensating to low oxygen under the conditions of our altitude classification rebreathing tests. The groups included high and low systolic pressures, high and low diastolic pressures, large and small pulse pressures, rapid and slow pulse rates, and cases of systolic pressure rise and fall on standing. A total of 554 cases were carefully examined and the mean or average reactions of each group determined. While each group was found to make the compensations to low oxygen in a similar manner and to tolerate equally low percentages of

oxygen, yet the plotted curves of the individual groups presented somewhat different pictures. The principal conclusion drawn was that none of the conditions studied appeared to place the heart and the nervous system under a handicap that is not present in average conditions of heart frequency and arterial blood pressures. It was shown that the rise in systolic pressure, at least under the conditions studied, is not great enough to place the heart under a dangerous strain.

The last paper published was "Physiological Effects of Altitude," by Edward C. Schneider, Physiological Reviews, October, 1921, volume 1, pages 631–659. This paper sums up the present-day opinions on the subject of the influence of high altitudes and low oxygen on mankind. In it are reviewed all of the experimental contributions of the last 15 years. The bibliography, which includes almost exclusively recent publications, includes 127 separate articles and books. It is the most complete paper yet written on the subject. After an explanation of anoxemia, the chief physiological factor of altitude, its effect on the aviator who experiences it for a short time, and on the mountaineer who through residence acclimates himself, Doctor Schneider discusses the respiratory response to altitude and the lowering of the CO_2 tension in the alveoli. He discusses the theory of O_2 secretion in the lungs and rejects it. He gives a careful explanation of the blood changes in acclimatization, the increase in hemoglobin, the effect of altitude on the H-ion concentration of the blood, and the mechanism by which this balance is maintained. He discusses the changes in the circulatory mechanism and the effect of physical exertion at high altitude and concludes as follows:

"Accepting then, for the present, only such factors as have been clearly demonstrated to serve in the compensation to anoxemia, we may rank them as follows: 1, increased respiration; 2, chemical alterations in the blood; and 3, increased hemoglobin. The respiratory change ranks first because by this means the partial pressure of the oxygen in the lungs is raised above what it would normally be at the altitude. This favors not only the absorption of oxygen in the lungs but also, after acclimatization, the passage of oxygen from the blood to the tissues. Since the alkalosis resulting from augmented breathing interferes with the passage of oxygen from the blood to the tissues, it can not be questioned but that the restoration of the normal H-ion content, by the elimination of the excess of alkali, constitutes a compensatory process of almost if not equal importance with the increase in breathing. The advantage gained by the increase in hemoglobin is not so obvious. Barcroft (six) finds the increase of but little value since even if it be sufficient to restore to normal the actual quantity of oxygen in 1 cc. of blood then, because of the decrease in oxygen pressure, the rate of dissociation will be so slow that it will not allow the oxygen to pass to the tissues in anywhere near the same proportions. Haldane (49) considers the advantage of the increase in hemoglobin due to the fact that the partial pressure of oxygen in the blood of the systemic capillaries is prevented from falling as low as it otherwise would."

There are now in press two articles that present physiological aspects of the work of the Medical Research Laboratory. Under the caption "The Human Machine in Aviation" the Yale Review will publish in nontechnical language descriptions of the physiological requisites of the successful pilot, of the compensations the body is called upon to make during flying, and lastly of the apparatus and tests used in the laboratory. The second contribution that is soon to appear is a chapter on "Climatology." This will be in an important book edited by Doctor Barker, of the Johns Hopkins Medical School.

The fire which destroyed the old laboratory building and equipment not only interrupted the investigations of the department but also destroyed the original data of parts of researches that were in progress at that time. Fortunately considerable portions of original data and many summaries of results were in two desks that were only partly burned. Because of this a statistical study begun more than a year ago has been carried to completion, and the results are in manuscript form almost ready for publication.

The investigation deals with the pulse rate and the three arterial pressures—systolic, diastolic, and pulse pressure—under four conditions, viz, recumbency, standing, immediately after a standard exercise, and two minutes after exercise. The major part deals with observations on 2,000 men, but a second group of 200 more unselected cases, who were examined even more carefully, has been used to check the results obtained from the large group. In addition, a study was made of two small groups (144 and 204 cases) of men, judged by clinicians at the time of examinations to be physically fit. The data are discussed from the standpoint of the distribution of cases, the amount of postural and exercise change, time required to return to normal after exercise, and the interdependence of the several factors. To determine the extent that one circulatory factor may be dependent upon others, two methods of study were used. In the first, the coefficients of correlation and other statistical relationships were calculated, and in the second, a selection of groups of cases showing extreme and opposite conditions with repect to one factor have been examined as to the mean condition and reaction of all the other circulatory factors. Interesting tendencies and relationships have been established that add a new viewpoint to our knowledge of commonly observed circulatory factors. The summary of results is too long to incorporate in this report. One advantage gained from this investigation is the opportunity it offers to check the values used in the rating tables employed in the determination of physical fitness and staleness.

Several researches are now nearing completion:

(1) The anoxic effects of rebreathing and the low-pressure chamber have been studied on several circulatory factors and conditions not regularly considered in the altitude classification examination. In one series of runs venous pressure was taken by the Hooker method every minute. In another series capillary blood pressure was taken by means of the Danzer-Hooker microtonometer, readings being taken as often as possible throughout the runs, averaging about every three minutes. The subjects for this series were selected with great care, only those whose capillaries showed clear and unclouded readings being chosen. The rate of blood flow through the hands was also determined by the use of a Stuart calorimeter, readings being taken every minute before, during, and for several minutes after each run. The hand volume was determined by the use of hand plethysmograph. A rough estimate of the relative output of the heart was determined as evidenced by a recoil-board

curve or by the gaseous content of the blood and the lungs. After the completion of several more low-pressure chamber experiments these data will be prepared for publication.

(2) The influence of a gradual increase in the carbon dioxide of respired air has been studied with respect to the pulse rate, the arterial blood pressures, venous blood pressure, capillary blood pressure, hand volume, blood flow through the hand, the alveolar air composition, and the rate, depth, and per minute volume of breathing. These data are ready to be written up for publication.

(3) The cardiovascular rating scheme for physical fatigue and efficiency that has been in use in the Air Service for several years has been under special consideration. Attention was given to influence of the diurnal circulatory changes, observations having been taken on a group of subjects hourly for a period of 24 hours; to the influence of eating, of drinking, of smoking, of exercise, and of various mild pathological conditions.

(4) A series of observations on the effect of passive change of posture on pulse rate and the arterial pressures was made by use of the orientator, observations being taken to show the effect of the horizontal and the inverted positions, as well as the reactions after a series of about 10 loops. This study was begun in 1920 and carried over into 1921. The work is not yet complete.

(5) A series of experiments showing the effect of the inhalations of pure nitrogen, including observations on pulse rate, arterial pressures, hand volume with the use of the hand plethysmograph, and blood flow by the Hewlett method, as well as rate and volume of respiration. This method brought about a rapid and acute oxygen want effect, the runs averaging in length from 40 to 80 seconds.

(6) Experiments with dermographic tracings were continued both in routine examinations on subjects for the 609 examination and in experimental work to try the effects of different localities of the body, different temperatures, humidities, varying amounts of pressure, and the effects of wind. The work has not yet reached the stage where definite conclusious may be drawn, but it can safely be said that the conclusions drawn by former observers are unwarranted, as they have not given due weight to the various factors affecting dermographia.

Other problems are now partially under way. (1) The influence of excessive breathing, resulting in a washing of carbon dioxide from the body, is being compared with the effects of low oxygen and of carbon dioxide. The first part of study will be confined to the circulation and respiration. This will be followed by (2) a study of the chemical urinary and blood changes resulting during (*a*) overventilation of the lungs, (*b*) exposure to a gradually increasing amount of carbon dioxide, and (*c*) during the low oxygen effects of rebreathing.

Work has also begun on a study of metabolism during exposure to low barometric pressure in the low-pressure chamber. For this purpose, a series of Douglas bags are being used to collect the expired air for intervals of 10 minutes. By this method it may be possible to determine why the breathing increases not only during an ascent, but for a while after an altitude has been reached; and then later, even though the altitude is maintained, decreases slightly. Later the influence of diet upon metabolism at high altitudes will be added to this study. The effects of physical work will also be considered. For this purpose a bicycle ergometer will be used so that the amount of work can be exactly determined.

In connection with the above research the following experimental runs were made:

In the study of anoxemia as follows:	
By inhalation of nitrogen	15
Recoil board in low-pressure chamber (of these the records of 25 were destroyed in the fire)	36
Recoil board with rebreather	21
Capillary pressure determinations on rebreather	10
Effects of carbon dioxide with determinations on pulse rate, respiration, arterial pressure, capillary pressure, venous pressure, hand volume, blood flow, alveolar air, recoil board, and psychological effects	52
Effects of forced breathing of atmospheric air with determinations of hand volume, venous pressure, and capillary pressure	4
Determinations of the time of return to normal of arterial pressure and pulse rate after one hour's exercise	8
Experiments on Schneider index to determine effects upon it, of meals, coffee, chocolate, tobacco, day-to-day variations, and variations in time of day	396
24-hour cycles of Schneider index	14
Dermographia—Routine	66
Dermographia—Experimental cases	21
Effects of passive changes of posture with orientator	14

2. Aviation Medicine.

At the same laboratory the work of the problem of the effect of low oxygen on the heart by the electrocardiogram was continued up until the time of the fire. These records and most of those obtained during the previous year were damaged or destroyed in the fire. The electrocardiograph was damaged in the fire, and it has not been possible to operate it until recently. It is hoped that this work can be completed early this coming year.

The paper entitled "A Sphygmographic Study of the Pulse During the Rebreathing Test," by Dr. C. W. Greene and Dr. N. C. Gilbert, which was outlined in the report of the Medical Research Laboratory and School for Flight Surgeons for 1920, was published in the Archives of Internal Medicine, volume 27, June, 1921. It was republished in the Air Service Information Circular, July 15, 1921, pages 115 to 120. "Studies on the Responses of the Circulation to Low Oxygen Tension" by the same authors, also outlined in the report of the Medical Research Laboratory and School for Flight Surgeons for 1920, were likewise published in the Archives of Internal Medicine, the American Journal of Physiology, and in the Air Service Information Circular of July 15, 1921, as follows:

"Changes in the Pacemaker and in Conduction During Extreme Oxygen Want as Shown in the Human Electrocardiogram." Archives of Internal Medicine, volume 27, April, 1921, and Air Service Information Circular of July 15, 1921, pages 75 to 106.

"Stages in the Loss of Function of the Rhythm Producing and the Conducting Tissue of the Human Heart During Anoxemia." American Journal of Physiology, volume LVI, page 468.

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The department of ophthalmology and otology and the department of psychology of the laboratory have collaborated in the problem on the determination of the effect of practise on nystagmus time. Preliminary work was completed for this experiment and apparatus being assembled, but it was destroyed by the fire and the work had to be done over again. The preliminary stage is again partly completed.

3. Neuro-Psychiatry.

The work in this department of the laboratory has been along the following lines:

1. Neuro-psychiatric examinations and personality studies.

2. A digest of the literature on neuro-psychiatry and a preparation of a series of papers on neuro-psychiatry to serve as a textbook in the School for Flight Surgeons.

3. A digest of the literature and analysis of the records and work of the laboratory on the subject of personality study. A paper has been prepared on this subject by Major Longacre and will be published shortly.

4. Clinical work.

In the routine work, special consideration was given personality study, in accordance with the revision made of proceedings and development along more comprehensive lines.

The series of papers alluded to above covers the entire study from descriptive psychology to and including personality study. The subject matter has been assembled from numerous sources and is presented in the form believed best suited to the needs of the flight surgeon and student within the limited time at his disposal.

The paper on personality study treats of—

(*a*) The meaning of personality.
(*b*) The purpose of personality study from the flight surgeon's viewpoint.
(*c*) Procedure in making personality study.
(*d*) Classification.

Each of these topics is elaborated in minutest detail with a wealth of material covering the subject from every point of view.

4. Ophthalmology and Otology.

At the laboratory further work on the perfection of ear plugs has been done and several hundred plugs have been sent out to the various flying fields. A report of this work, together with a description of the method of making the plugs, has been prepared by Major Tefft and Miss Stark, and will be published shortly. There are two types of plugs, one for summer use and the other for winter use, the difference being in the consistency of the plugs. They are manufactured from a mixture of beeswax and parresine on a core of lamb's wool. The plugs seem to keep out satisfactorily all the noise from the roar of the motor without interfering with the ability of the pilot to detect a skipping in his engine. They eliminate the temporary deafness which always results after prolonged rides in any plane or short rides in bimotored planes.

A study of the "speed of accommodation" in relation to the various phases of the eye examination given to fliers has been completed on 60 subjects, and a paper entitled "The Speed of Accommodation as a Practicable Test for Fliers," by Major Tefft and Miss Stark is now ready for publication.

The apparatus used in determining the speed of accommodation is the tachistoscope developed in 1918 by Prof. C. E. Ferree, of Bryn Mawr College. It is devised so that three test letters (two near, one at the left, the other at the right, and one far in the middle) are exposed simultaneously to the observer and are then cut off from his view one at a time in a fixed order. This is done by means of three sets of aluminum disks "of variable open and closed sectors turned by means of a bar fastened at its center to the axle to which the disks are attached and provided with adjustable weights on both arms." The two sets of disks which expose and exclude the near test letters are attached to the axle at the same point, but the one for the left letter is of shorter radius. The third set of disks controlling the exposure of the far test object is fastened to the axle behind the near test cards. "The length of exposure can be varied either by changing the width of the open sector or the position of the weights on the arm" of the bar.

The system of disks with the propelling bar operates behind a cardboard screen fastened to the framework of the apparatus. At the level of the test objects a narrow slit is cut in the screen through which the observer views the test letters.

The test letters are the illiterate E's mounted so that they can be rotated to point in the different directions, up, down, right, and left. The height of the near E is 0.8 mm., that of the far one 11.7 mm. Illumination for the near test cards is provided by a tubular tungsten lamp fastened to the top of the frame of the apparatus. This throws the light on the back of the cardboard screen and from there it is reflected to the test cards. Direct illumination on the far test card comes from a tungsten lamp mounted in a reflector.

In giving the test the subject is seated 30 cm. from the near test objects and 6 meters from the far one, with his head held in position by a Troland headrest. After a completed exposure he is required to report the direction in which each of the E's points. In order to perceive these successfully, he must first focus on the near E at his left, then adjust for the far E in the center, and finally accommodate for the near E at his right. After a short practice period the exposure times for each letter are gradually shortened until the subject's maximum speed is obtained. The various exposures, near, near to far, near to far and back to near, are recorded in terms of degrees of open sector and later converted into time by a process of calibration.

In view of the following facts it is not recommended that the test for speed of accommodation be incorporated at this time in the 609 examination. The apparatus in its present form is cumbersome and its operation requires too specialized a technique for use in a routine examination. Many subjects find difficulty in adjusting to this particular test situation. The memory factor seems to be almost as important as proper eye functioning. The test as given undoubtedly places much greater strain on the eyes than is required in any flying situation. Finally with the exception of presbyopic cases those who possess a slow speed of accommodation seem to possess other visual deficiencies which can be more easily detected.

Two papers on the Retinal Sensitivity Apparatus, discussed in the report of the Medical Research Laboratory and School for Flight Surgeons for 1920, have been written

by Dr. P. W. Cobb and M. W. Loring, formerly of the staff, on their work with this apparatus while at the laboratory. One is entitled "A Method for Measuring Retinal Sensitivity." It was published in the Journal of Experimental Psychology, June, 1921. The other paper will be published shortly and is entitled "Individual Variations in Retinal Sensitivity and Their Correlation with Ophthalmologic Findings."

The study of depth perception referred to in the report of the Medical Research Laboratory and School for Flight Surgeons for 1920 is considered under Aviation Psychology.

The research work planned for the past year on nystagmus time was interfered with by the fire, and reference to the progress of this work has already been considered under Aviation Medicine.

The work planned to determine the factor of the association of reaction time with depth perception and the effect of altitude on hearing and vision has been impossible because of the destruction of apparatus and equipment caused by the fire. This work is now ready to go ahead again.

5. Aviation Psychology.

Several complete standard psychological set-ups have been assembled—one for use at the laboratory to replace one destroyed by fire, the others to provide practice for the student officers or to be sent to branch units as required.

The statistical study of types of motor responses shown during the first three minutes of the rebreathing test was extended to include 600 records from other flying fields, in addition to the 600 records originally used. Comparisons between the groups selected according to the type of response were made with respect to the character, quality, and length of run, and the final oxygen, rating, and score. The completion of this work was hindered by the fact that a large part of it was destroyed by fire and water, and the material had to be reassembled, recalculated, and the curves redrawn. The study is now complete.

The majority of reactors present a type of motor response which is steady, slow, and accurate, in contrast to the other large group of reactors whose responses are impulsive, hesitant, and inaccurate. Comparisons of these two classes show the former to be superior in every way. The initial failure of attention and the ability to coordinate properly and the complete failure of these faculties occur later and at lower oxygen per cent than is the case in the second group; the run is of longer duration and the final oxygen per cent is lower. Of the first group, 60 per cent are rated "A," 31 per cent "B," and 8 per cent "C" as compared with the second group, of which 30 per cent are rated "A," 48 per cent "B," and 22 per cent "C." In as far as ability to preserve his attention and voluntary control at altitudes, as shown by the rebreathing test, is concerned, these results indicate that the reactor whose responses are steady and accurate is superior to the one who shows impulsive, hesitant, and inaccurate tendencies.

A paper on the "Psychological Effects of Aviation on the World," was prepared at the request of the Military Intelligence Department, by Miss Deyo.

By the departments of aviation psychology and aviation physiology of the laboratory, a statistical study of the relationship between pulse increase, respiration response, final oxygen, and the oxygen percentage at which complete failure of motor coordination and attention occurred, as shown on the rebreather, was completed. From the same records another study was made of the final oxygen to (1) systolic increase, (2) diastolic increase, (3) pulse pressure increase, and (4) respiration response. The results of these two studies have not yet been written.

Suitable psychological tests for use in the low-pressure chamber have been devised. It is planned to have these experiments test the degree and fluctuation of attention, degree of motor incoordination, powers of association and retention at varying oxygen levels, and the power properly to perceive and retain impressions at a high altitude. These tests have been tried out under normal conditions upon a number of subjects preliminary to their use in the low-pressure chamber.

A paper called "Monocular and Binocular Judgment of Distance," based upon data collected by Capt. B. H. Palmer, formerly of the ophthalmology department, was written by Miss Deyo and will be published shortly. The subjects, who were Army officers and men, were given the routine eye examination for fliers, which included the visual acuity for each eye, the angle of convergence, judgment of depth perception using binocular vision, and, in addition, judgments of depth perception using monocular vision. There are such great differences in judgments of depth perception made with monocular vision and with binocular vision (the former being uniformly poorer) that it is evident that good binocular vision is necessary for accurate judgment of distance, and the results show that the better the visual acuity the more accurate the depth perception judgments tend to be.

Two papers reviewed in the report of the Medical Research Laboratory and School for Flight Surgeons for 1920 have been republished in the Air Medical Service Information Circular of July 15, 1921. They are:

"Psychological Research in Aviation in Italy, France, England, and the A. E. F.," by F. C. Dockeray and S. Isaacs, formerly of the laboratory staff, pages 26 to 37.

"Psychological Effects of Deprivation of Oxygen. Deterioration of Performance as Indicated by a New Substitution Test," by H. M. Johnson and F. C. Paschal, formerly of the laboratory staff, pages 38 to 72.

6. Miscellaneous.

A paper was published this year in the Air Service Information Circular for July 15, 1921, on pages 134–139, entitled "A Brief Note on the German Liquid Oyxgen Apparatus." This was compiled by Dr. George B. Obear while attached to the laboratory staff, and published following his discharge from the service. The paper gives a detailed description of three types of the apparatus received at the laboratory and summarizes the advantages and disadvantages of a liquid-oxygen apparatus.

The plans for the Eagle airplane ambulance, mentioned in the report of the Medical Research Laboratory and School for Flight Surgeons for 1921, were carried out and the alterations made. The ship carried four patients in litters and two sitting. There was also room for a surgeon next to the pilot, and a first-aid cabinet was installed near the front of the cabin. Unfortunately before the ship was thoroughly tested out as an ambulance it was wrecked.

There are two fields of usefulness for airplane ambulances. One is in attending crashes. For this purpose the machine must be small and easily handled. It will be able to carry only one, or at the most two patients. Crashes are

apt to happen in places where an airplane can not make a satisfactory landing. The other field is in transporting patients from one hospital to another or from the front to the rear in war time. It is believed this will prove to be the field of greatest usefulness. Large planes can carry several patients and carry them in comfort with less danger and with greater rapidity than any motor ground ambulance can ever hope to do.

II. SCHOOLS OF INSTRUCTION.

1. Instruction for Flight Surgeons.

The only school of instruction is the School for Flight Surgeons located at the Medical Research Laboratory, Mitchel Field. This school is unique and a description of its organization and work would seem worth while. The school is located at and operated by the personnel of the laboratory. It has a commandant, who has charge of the instruction and administration; assistant commandant and director of the department of neuro-psychiatry, who conducts the details of administration of the school and acts as librarian; executive and supply officer, who also acts as secretary of the school and is custodian of its records. The faculty board consists of the commandant, ex-officio, assistant commandant, secretary, and directors of the departments. The school is divided into the departments of aviation medicine, aviation psychology, ophthalmology, and otology, aviation phychology, neuro-psychiatry, supply and engineering, and administration and equipment. The board has charge of all matters relative to the standing, rating, and efficiency of all students, and also acts on such other matters as may be referred to it by the commandant. The directors of the departments and certain assistants are instructors.

The course covers three full months, and classes are held from 9 a. m. to 4.30 p. m., except Saturday, when the hours are from 9 a. m. to 12 m. The course consists of lectures, clinics, quizzes, practical work, demonstrations, prescribed and collateral reading. At the end of the course a general qualifying oral examination is given by the faculty board. Each student must be qualified to perform the flying examinations, both 609 and rebreather, and must obtain an average of 80 per cent in all subjects and not fall below 75 per cent in any of the five major subjects. The student who attains an average of 90 per cent or over is graduated with honor. In addition, each student is rated on his aptitude for flight surgeon's work, regardless of his professional ability. Rating are made on the scale of "A" above average, "B" average, and "C" below average.

The faculty board consists of the following:

Maj. L. H. Bauer, commandant and director of the department of administration and equipment for flight surgeons.

Maj. Lloyd E. Tefft, director of department of ophthalmology and otology.

Maj. R. F. Longacre, assistant commandant and director of department of neuro-psychiatry.

Capt. J. B. Powers, director of department of aviation medicine.

Dr. E. C. Schneider, director of department of aviation physiology.

Miss Barbara V. Deyo, director of department of aviation psychology.

Miss Dorothy Truesdell, acting director of department of aviation physiology.

The following have acted as instructors in addition to the members of the faculty board:

Capt. Ira F. Peak, instructor in neuro-psychiatry.

Miss Elizabeth K. Stark, instructor in ophthalmology and physiological optics.

The synopsis of the course follows:

Department of Aviation Physiology.

The lecture covers the following:

Introductory and general.

Physiological aspects of aviation.

Physiological effects of climatic factors other than altitude.

The hematorespiratory function of the blood.

Laws of respiratory absorption and dissociation.

The demand for oxygen and rate of oxygen consumption.

Anoxemia; classification and methods of producing each kind.

Altitude sickness and the symptoms of other low oxygen experiences.

The compensations to low oxygen, with comparisons of the temporary and permanent varieties of reaction in the following:

- Respiration.
- Blood.
- Hematorespiratory function of the blood.
- Circulation.
- Metabolism.

Physiology of muscular exercise, including muscles, body temperature, respiratory, circulatory, and metabolic changes.

Physical fitness. Comparison of trained and untrained.

Fatigue and staleness.

The measurement of fatigue and fitness.

Types of response in rebreathing.

Color reactions on the rebreather.

The practical work includes brief lectures, demonstrations, as well as practical work on the following:

The Henderson rebreather and the Larsen rebreather—

The work includes the set-up, calibration, preparation, and operation in practice and official runs of both machines, including the work of the physiologist, machine men, and the blood-pressure man.

Gas analysis and the preparation of solution and set-up of apparatus.

The Schneider index.

Plotting and preparation of rebreathing records.

Rating.

The low-pressure chamber—

(*a*) Pulse and blood pressure.

(*b*) Alveolar air.

Consideration of the English tests for fliers, and also Dreyer test, Martin test, and other tests.

DEPARTMENT OF AVIATION MEDICINE.

The lectures and practical work cover the following:

1. Cardiac pathology.
2. Sounds and murmurs, normal and abnormal.
3. Valvular defects.
4. Affections of heart muscle associated with retrograde changes, infiltration, and subsequent repair.
5. Affections of the heart due to exogenous and endogenous influence.
6. Myocarditis in acute infection.
7. Anaphylactic heart.
8. The arrhythmias.
9. Neuro-circulatory asthenia.
10. General physical examination and physical examination for flying.
11. The rebreather and low pressure chamber from a clinical standpoint.
12. X ray and fluoroscopy.
13. The electrocardiograph and the polygraph.
14. The heart in aviation.
15. Series of clinics at Bellevue Hospital, New York City.
16. Frequent demonstrations and quizzes.

DEPARTMENT OF AVIATION PSYCHOLOGY.

The lectures cover the following:

1. The standard psychological test.
2. General psychological principles.
3. Psychological tests for efficiency.
4. Apparatus and wiring.
5. Emotion and its relation to efficient reaction.
6. Psycho-physical tests—
   (*a*) American.
   (*b*) Foreign.
7. Effects of alcohol and caffeine on efficiency.
8. Tests used by psychologists in A. E. F.
9. Rating.

There is in addition practical work with the rebreather and the student acts as psychologist on as many official runs as possible, also practical work on apparatus and wiring, and on psycho-physical tests.

DEPARTMENT OF NEURO-PSYCHIATRY.

Psychiatry.—Lectures and quizzes on the following:

1. Descriptive and genetic psychology.
2. The nature, causes, general symptomatology, and classification of mental disorders.
3. Dementia precox.
4. Manic depressive psychosis.
5. Paresis.
6. The paranoias.
7. Psychoses associated with organic diseases and injury of the brain.
8. Symptomatic, infection-exhaustion, and toxic psychoses.
9. Presenile, senile and arteriosclerotic psychoses.
10. Borderland and episodic states comprising constitutional psychopathic inferiority and the psychoneuroses.
11. Defective mental development.
12. Methods of examination.
13. The neurological examination for flying.
14. Personality study.
15. Practical work and a series of clinics at Bellevue Hospital and Brooklyn State Hospital.

Neurology.—The studies in neurology comprise cerebral and segmental localization, conduction pathways, and nerve distribution as developed by the intensive studies made of pupillary reactions, station, gait, reflexes, tic, and tremor; the significance of the normal and abnormal findings in the complete neurological examination.

Because of the intensive nature of the course, it has been found necessary to present the subject matter along lines differing somewhat from those followed in the usual textbooks. Fundamentals are presented clearly and concisely with the fullest development of the subject possible in the time allotted. The papers already referred to under "Research" serve as the textbook.

DEPARTMENT OF OPHTHALMOLOGY AND OTOLOGY.

Ophthalmology.—Lectures, quizzes, demonstration, and practical work. This includes practice in the ophthalmological section of the 609 Examination, including set-up and use of apparatus, ophthalmoscopy, and retinoscopy.

The importance of the eye in flying is emphasized.

The following subjects with their special adaptations to flying are covered in the lectures and quizzes.

- Anatomy of the eye.
- External, subjective and objective examination of the eye.

Brief consideration of diseases of:

- The lids.
- Lachrymal apparatus.
- Orbit.
- Conjunctiva.
- Cornea.
- Sclera.
- Iris.
- Ciliary body and choroid.
- Vitreous.
- Lens.
- Retina.
- Optic nerve.
- Glaucoma.
- Disturbance of vision.
- General optical principles.
- Refraction.
- Retinoscopy.
- Accommodation.
- Convergence.
- Extrinsic muscles.
- Disturbances of motility.
- Ocular manifestations of general diseases.

Otology.—The lectures and practical work cover the following:

- Anatomy and histology of ear, nose, and throat.
- Pathology and treatment of ear, nose, and throat, conditions commonly met.
- The inner ear—
  - Reaction, nystagmus, past pointing, falling.
  - Brain tracts.
  - Associated centers, etc.
- The 609 examination.
- Orientator.

DEPARTMENT OF ADMINISTRATION AND EQUIPMENT FOR FLIGHT SURGEONS.

Lectures and demonstrations on the following:

1. The various gas and liquid oxygen supply apparatuses.
2. Methods of testing the instruments.
3. Proper installation.
4. Advantages and disadvantages of the various instruments.
5. Comparison of the foreign and American flying examinations.
6. Aviation accidents.
7. Duties of the flight surgeon.
8. Paper work and practical work on the flying field.
9. Work and records of branch and field units.
10. The equipment for flight surgeons, rebreather, and field units.

There is prescribed and collateral reading in connection with each subject.

I desire to acknowlege the courtesy rendered by, and the obligations of the school to the members of the staffs of the Bellevue Hospital, New York City, and the Brooklyn State Hospital.

2. INSTRUCTION FOR ENLISTED MEN.

This school has been nonoperative during the past calendar year, as no students were detailed for instruction. It is believed this phase of work should be further developed, for flight surgeon's assistants and assistants for rebreathing units can be more satisfactorily trained at the laboratory than by the individual flight surgeon. These men should be trained as follows:

A. *Department of aviation physiology.*—Practical work on the Henderson and Larsen rebreathers, including set-up, calibration, preparation, and operation of both machines; the taking of blood pressure and pulse; gas analysis and the preparation of solutions, and set-up of apparatus; plotting and the preparation of rebreather records; the Schneider index.

B. *Department of ophthalmology and otology.*—The set-up of apparatus and the operation of the Barany chair; the recording of the results of the examination.

C. *Department of administration and equipment for flight surgeons.*—The paper work of a flight surgeon's office; the paper work of rebreathing units; care and set-up of equipment for flight surgeons, rebreathing units, and field units.

The course should cover a period of two months.

3. LIBRARY.

The library of the laboratory and school, which is under the immediate charge of the assistant commandant and the library committee, had to start all over again, following the fire.

A good working library is essential both for research and for the school. Effort is being made to procure all articles concerning aviation medicine, and also books and periodicals relating to the specialties allied to aviation medicine. Special attention is paid to physiology, physiological chemistry, neurology, psychiatry, psychology, ophthalmology, otology, roentgenology, and cardiology.

There are at present 740 volumes and pamphlets in the library.

III. ROUTINE WORK.

It seems worth while to outline the routine work which is done in aviation medicine. A great part of this is done at the Medical Research Laboratory. However, flying examinations are done at all Air Service stations by various flight surgeons, and their work is exceedingly important and much valuable information is derived from their findings on these examinations and in their care of the fliers.

1. PHYSICAL EXAMINATIONS.

All the physical examinations for flying, according to Form 609 W. D., A. G. O., for the personnel of Mitchel Field and for this section of the country, are made at the laboratory. Likewise all altitude classification tests are made there. Various special examinations are made, and border-line cases have been referred there for examination and recommendation.

All the physical examinations for flying are made by the specialists in the various departments. A board of officers from the departments of aviation medicine, neuropsychiatry, and ophthalmology and otology considers the case of every applicant who is rejected on any point in the 609 examination. A recommendation is made to the Chief Surgeon, Air Service, for or against a waiver in that particular case. In addition to the requirements of the 609 examination, each subject is given a Schneider index, his heart is fluoroscoped, an X-ray picture is taken of the chest, and also one is taken of the head to determine the condition of the sinuses. These X-rays are filed with his record for future reference. A personality study is likewise made of every candidate. The classification tests are conducted in conjunction by the departments of aviation medicine, aviation physiology, and aviation psychology.

2. BRANCH LABORATORIES.

There are branch rebreathing units maintained at Kelly, March, and Carlstrom Fields, and at the Army Medical School, where altitude classification tests are made. These units are supplied by the laboratory. All their records are first forwarded to the laboratory for examination and revision to insure accuracy and uniformity in the tests and ratings. These records are carefully examined and checked in the departments of aviation medicine, aviation physiology, and aviation psychology.

3. X-RAY AND PHOTOGRAPHY.

The department of aviation medicine of the laboratory has a subsection devoted to X-ray and photography. This section carries on research in connection with the department of aviation medicine and other departments. The electrocardiograph is used for both research and instruction and in examinations. Photographic work consists of:

Still photography of apparatus and equipment.
Charts both for publication and instruction purposes.
Motion picture photography for the same purposes.

A summary of the X-ray work is as follows:

X-ray pictures, 410.
Fluoroscopy on all 609 examinations.

A summary of photography is as follows:

Charts photographed for reproduction, 92.
Still photography of apparatus and equipment, 29.
Prints of charts and stills, 318.
Motion pictures, approximately 5,300 feet.

In connection with motion pictures a complete record was made of the 609 examination from start to finish, all of which was destroyed in the fire, and which will have to be made over again.

A summary of the routine work of the laboratory follows:

Flying examinations according to Form 609 W. D., A. G. O., 199.
Altitude classification tests, 55.
Altitude classification tests from branch units revised at the laboratory, 162.
Personality studies, 207.
Special examinations, approximately 60.
Electrocardiograms, 475.
X-ray and photographic work as outlined above.

These are all in addition to the experimental examinations mentioned under the head of "Research."

The Air Service Information Circular of July 15, 1921, was proof read at the laboratory.

Work has been started on drawing up a set of training regulations for airplane ambulances.

4. Personnel.

It will probably be interesting to know how great a personnel has been necessary to carry on the work outlined above at the laboratory and school.

(*a*) officer personnel.

The number of the permanent officer personnel throughout the year was 8. Of these 1 was on sick report the entire year. Of the other 7, 1 was commandant, 1 executive and supply officer (an administrative corps officer), 3 are directors of departments, and 2 assistants in departments.

All of the medical officers are qualified flight surgeons. It is important that the officers selected for duty in the organization are well qualified for work in the particular departments to which they are to be assigned. Every officer here should be qualified in one of the particular specialties that are important to aviation medicine.

(*b*) civilian personnel.

There are 18 civilian employees at present in the laboratory; 7 are scientific, 6 technical, 3 clerks, and 2 janitors. Two of the departments have only civilians among the personnel. These are the departments of aviation physiology and aviation psychology. The work of these departments is so special and technical that no officers or enlisted men are qualified for it. The scientific personnel have been at the laboratory from a year and a half to two and a half years. They are well trained and thoroughly familiar with their work. Their qualifications are special and they could not be replaced.

IV. THE FUTURE OF AVIATION MEDICINE.

Future work in this subject seems endless. There are fields which have been touched only lightly or not at all. For example, the effect of wind, one of the most trying things the aviator has to combat, is a subject about which very little is known. It is contemplated in the future to build a wind tunnel in the Research Laboratory and to do experimental work along this line. The subject of aviator's clothing is another which is not thoroughly satisfactory. There are still factors in connection with altitude that are not satisfactorily settled. The question of reaction time, particularly in estimating distance and in certain other factors in the physical examination, is important, undoubtedly, and yet there is very little on which to base a statement about it. The effect of cold is another subject on which work has not yet been started. The Medical Research Laboratory has a refrigerating apparatus in connection with its low-pressure chamber with which it is intended to experiment in order to determine satisfactorily the effect of not only cold but cold combined with altitude. The subject of fatigue has yet many sides to be investigated.

The National Research Council has appointed a large committee to consider the feasibility of an extended investigation of the relation of air to health. After a comprehensive plan of study had been formulated, a subcommittee consisting of Prof. W. H. Howell, of Johns Hopkins University, Dr. Yandell Henderson, of Yale University, and Dr. E. C. Schneider, of Wesleyan University and director of the department of aviation physiology at the Medical Research Laboratory, was appointed to take charge of the research experiments. The subcommittee has proposed as the first problem for investigation, "The physical effects of various combinations of temperature, moisture, and air movement." Since the effects of temperature and wind are pertinent to the health of the aviator, and are problems which the laboratory has had in view for some time, it is believed that the department of physiology of the laboratory should cooperate with the committees of the National Research Council and carry out there some of the phases of this program of investigation. The low-pressure chamber with its refrigerating equipment meets an important requirement for experimental observation. One of the prime objects of the National Research Council is to coordinate research throughout the country. It is believed that this organization has an opportunity now, not only to produce work which will be of benefit to aviation, but of value to the whole world.

The School for Flight Surgeons needs but little comment. It is believed it has now reached a point where its value is recognized and where it is on a solid foundation. Little change is contemplated in the course in the near future, except such additional information as may be acquired through research. It is believed the question will soon arise, however, as to whether or not the course should be extended beyond the allotted period of three months. The amount of work crowded into the three months is very great. The student's entire time is so occupied that he has difficulty in keeping up with the pace set.

It is believed that one way in which the laboratory could be of greater value to the service has not been properly developed, and that is its relation to the flight surgeon in general. Effort has been made to keep in touch with the flight surgeon after he graduates from the school, and this effort has met with some success in some instances. It is believed, however, that if some arrangement could be made whereby flight surgeons in the field were called upon to report periodically on certain phases of their work to the laboratory, that much valuable information might be acquired. In the reports of the Medical Research Laboratory and School for Flight Surgeons for 1919 and 1920, recommendation was made that once a year some officer from the laboratory be detailed to visit the branch rebreathing units to inspect the work being done there and

coordinate it with that of the main laboratory. In addition, he could check the work of the flight surgeon. It is believed that the work of the branch units and that of the flight surgeons could be made more efficient by their being kept in closer touch with the laboratory. Coordination brings about that standardization of work which is both desirable and essential in the Air Medical Service.

The order issued about a year ago removing flight surgeons from flying status has, as prophesied, worked serious harm. Medical officers are less anxious for the work when they can not be placed on flying status, and their value and enthusiasm are decreased. There are certain phases of flight surgeons' work that can be accomplished only by a personal knowledge of flying. It is not necessary that all flight surgeons become pilots, but it is absolutely necessary that they have some practical experience in the air. It is not possible for them to have as good an interpretation of the problems of flying from the medical side of aviation without this practical experience. It is certainly most unjust to expect these officers to fly regularly and frequently as they should do, unless they can receive the same compensation that other officers receive.

I desire to express my thanks to Dr. Edward C. Schneider, Miss Dorothy Truesdell, Miss Barbara V. Deyo, and Miss Elizabeth K. Stark for assistance in compiling this article.

THE SPEED OF ACCOMMODATION AS A PRACTICABLE TEST FOR FLIERS.

By Maj. Lloyd E. Tefft, *Medical Corps*, and Elizabeth K. Stark, *Department of Ophthalmology, Medical Research Laboratory and School for Flight Surgeons, Mitchel Field, Long Island, N. Y.*

PURPOSE.

It was believed that the speed of accommodation of the eyes possessed by a pilot played an important part in flying, especially in combat work, landings, and other manoeuvers in which it was necessary for a pilot to focus his vision from far to near objects and vice versa.

Research work was accordingly undertaken in this laboratory to ascertain the relationship, if any, of the speed of accommodation to other properties of the eyes, such as visual acuity as manifested by the ability to read Snellen test type at 20 feet; depth perception as elucidated by the Howard-Dolman depth perception apparatus; the power of accommodation as determined with the Prince rule; the strength of the internal and external recti muscles as measured by the angle of convergence and the power of prism divergence; retinal sensitivity as obtained from the Cobb retinal sensitivity apparatus. For this purpose 60 subjects were examined and the results charted and correlated with the various parts of the eye examination given to fliers as well as with the retinal sensitivity test.

The subjects, according to the results of the eye examination were divided into three classes: (1) A general classs embracing both those qualified, and those disqualified because of ocular defects other than speed of accommodation, (2) those qualified and (3) those disqualified by the examination. Means were established on each of these classes to determine if any candidates, otherwise qualified for flying, would be disqualified because of possessing a low speed of accommodation, and to establish, if possible, a lower speed limit for all cases presenting themselves for examination. Also it was desired to ascertain if there were any candidate otherwise disqualified possessing a high speed of accommodation.

TECHNIQUE.

The apparatus used in determining the speed of accommodation was the tachistoscope developed by Prof. C. E. Ferree, of Bryn Mawr College.[1]

It is devised so that three test letters (two near, one at the left, the other at the right, and one far, in the middle) are exposed simultaneously to the observer and are then cut off from his view one at a time in a fixed order. "This is done by means of light-weight disks of variable open and closed sectors turned by means of a bar fastened at its center to the axle to which the disks are attached and provided with adjustable weights on both arms." "The length of exposure can be varied either by changing the width of the open sector or the position of the weights on the arms."

The test letters used were the illiterate E's, mounted so that they could be rotated to point in different directions. The working distance of the far test object was 6 meters and of the near test objects 30 centimeters; the visual angles subtended in each case were 6 minutes 42 seconds and 9 minutes 10 seconds. The brightness of the far test card was 10.40 candles per square foot; of the right and left test cards 1.68 and 1.16 candles per square foot, respectively.

After a completed exposure the subject was required to report the direction in which each of the E's was pointed. In order to perceive these successfully, he had first to focus on the near E at the left, then adjust for the far E in the center, and finally accommodate for the near E at the right. After a short practice period with slow speed, the exposure times for each letter were gradually shortened until the point was reached where the subject could just discriminate each. Then three correct judgments out of a possible five for a given setting of disks were required. The various exposures; near, near to far, near to far and back to near were recorded in terms of degrees of open sector and converted into time by a process of calibration. In working up the results, however, only the total time required for the complete excursion was used.

RESULTS.

The two curves show the distribution of results for the 60 cases examined in our series and for the 100 cases examined by Goodall.

Table I gives the means and medians together with the probable errors of the results obtained. The means and medians of Goodall's cases, 89 of whom were aviators, have been computed and added for their comparative value.

Table Ia shows these same central tendencies when extreme cases have been omitted by Chauvenet's criterion.

Table II gives correlation values between speed of accommodation and the results of the various phases of the eye examination for fliers as well as with a retinal sensitivity test and with age.

Table III gives the speed of accommodation and the refractive correction of those cases disqualified because of high refractive error.

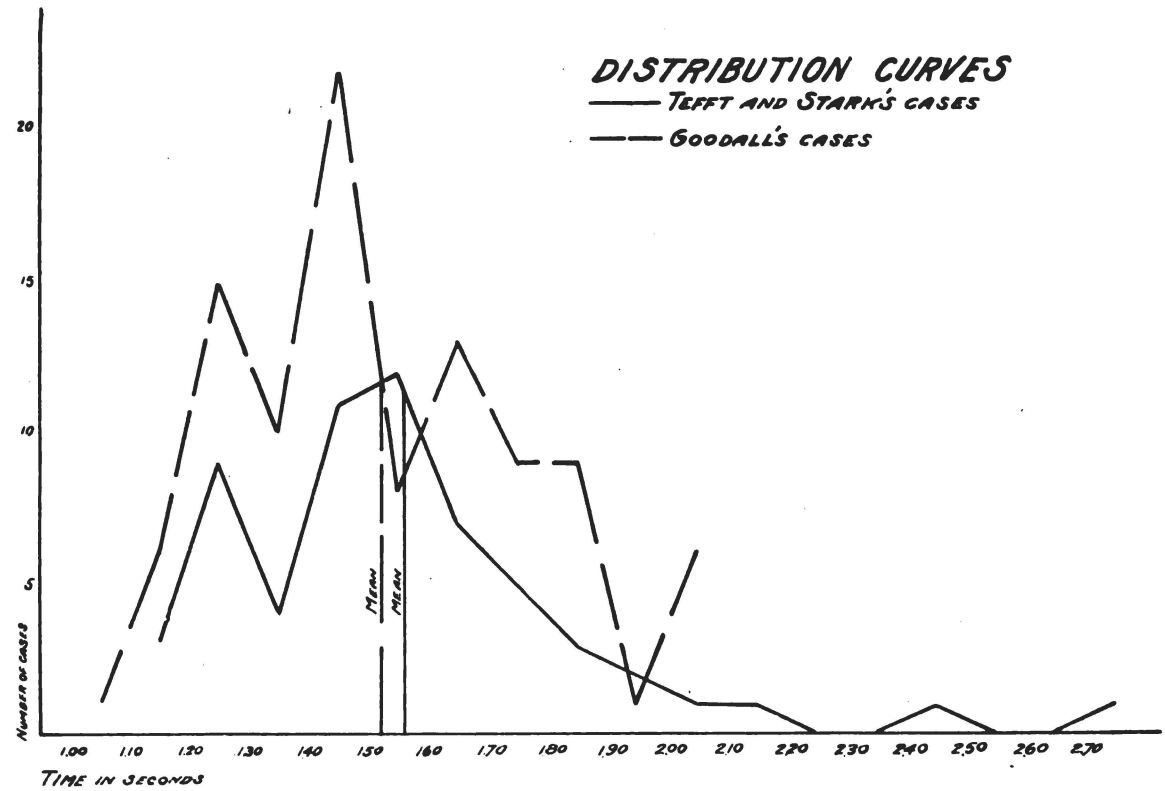
[1] For a detailed description of the apparatus, see C. E. Ferree and Gertrude Rand, The Inertia of Adjustment of the Eye for Clear Seeing at Different Distances, American Ophthalmological Society s Transactions, 1918. Edwin B. Goodall, The Speed of Accommodation, Air Medical Service Circular, March, 1920.

DISCUSSION AND INTERPRETATION OF RESULTS.

As appears in Tables I and Ia and the distribution curves, our results were essentially the same as those obtained from Goodall's data. The eliminating of extreme cases from our group renders our mean almost identical with that obtained from his results. Although the mean time for the 16 cases which were disqualified by the eye examination given to fliers is somewhat higher than that for the 44 cases which were qualified, this difference as measured by its probable error is not great enough to be significant.

TABLE II.

Type of test.	Number of cases.	r	P.E.$_r$
Visual acuity R. E.	60	0.307	±0.079
Visual acuity L. E.	60	0.326	±0.078
Depth perception	60	0.336	±0.077
Prism divergence	60	0.009	±0.087
Av. accommodation for 2 eyes	60	0.369	±0.075
Angle of convergence	60	0.240	±0.082
Retinal sensitivity	60	0.167	±0.084
Age	60	−0.331	±0.078
Age, cases qualified by eye exam	44	−0.526	±0.075



Two cases whose speed was so slow as to permit their elimination on the basis of Chauvenet's criterion were qualified by the examination. This was undoubtedly a matter of age, as the high negative correlation between speed and age (Table II) becomes practically negligible when these cases are eliminated (Table IIa). The two men were 37 and 39 years of age, and their slow speed is interpreted as being indicative of the initiation of presbyopia.

TABLE I.

	Number of cases.	Mean P. E. secs.	Median P. E. secs.
Entire group	60	1.563±0.026	1.525±0.032
Qualified by eye exam.	44	1.536±0.031	1.500±0.039
Disqualified by eye exam.	16	1.637±0.044	1.575±0.055
Goodall's group	100	1.526±0.017	1.482±0.017
Aviators Goodall's group	89	1.505±0.015	1.468±0.022

TABLE Ia.—*Extreme values omitted by Chauvenet's criterion.*

	Number of cases.	Mean P. E. secs.	Median P. E. secs.
Entire group	58	1.528±0.020	1.517±0.025
Qualified by eye exam.	42	1.496±0.021	1.498±0.026

TABLE IIa.—*Extreme cases of Table II omitted by Chauvenet's criterion.*

Type of test.	Number of cases.	r	P.E.$_r$
Visual acuity, R. E.	57	0.235	±0.084
Visual acuity, L. E.	57	0.406	±0.075
Depth perception	57	0.244	±0.085
Prism divergence	57	−0.052	±0.089
Av. accommodation	58	0.204	±0.085
Angle of convergence	58	0.250	±0.083
Retinal sensitivity	57	0.210	±0.085
Age	58	−0.097	±0.088
Age, qualified by eye exam.	42	−0.166	±0.111

TABLE III.

Subject.	Time secs.	Refraction. R. E.	Refraction. L. E.
G.B.M.	1.226	+2.25 Sp.	2.50 Sp.
J.J.M.	1.468	+1.25 Sp.+0.25 cyl. ax. 90°.	1.25 Sp.+0.75 cyl. ax. 90°.
J.H.H.	1.487	+3.00 Sp.	3.00 Sp.
H.T.D.	1.542	−0.75 Sp.+1.50 cyl. ax. 90°.	−0.75 Sp.+1.50 cyl. ax. 90°.
A.C.M.	1.698	+2.25 Sp.+0.50 cyl. ax. 90°.	2.25 Sp.+0.50 cyl. ax. 90°.
V.T.S.	1.995	−1.75 Sp.	−1.75 Sp.

It has been suggested that these two cases might have been disqualified if the disqualifying limit for the power of accommodation were made more rigid. At present, a leeway of two diopters above or below the normal for each age as determined by Duane, is allowed. The normal power of accommodation for the ages 37 and 39 according to Duane's table is 6.8 and 6.2 diopters, respectively. The actual power of accommodation of the two cases in question was for the one case, 6.5 D both eyes, and for the other, 5.25 D., R. E. and 5.00 D., L. E. Although both of these cases are below the normal, they are well within the two diopter limit set. Where the question of speed is not involved the eye can, no doubt, in certain cases, exercise a degree of accommodative effort sufficient to overcome a certain amount of its accommodative deficiency.

Visual acuity, depth perception, and extent of accommodation all show a moderate degree of correlation with speed, but with the omission of extreme cases the correlation between the visual acuity of the left eye and speed of accommodation becomes the most significant. The power of prism divergence bears no relation at all to speed of accommodation as judged from the value of r obtained; and the correlation between retinal sensitivity and speed is not high enough to be significant.

It will be seen from Table III that the six cases disqualified because of high refractive error have a wide range of speed, one of them falling in the group of the best 15 per cent of the cases and another among the poorest 15 per cent. These few cases show no correspondence between decreased speed and extent of refractive error.

If we were to adopt 2 seconds as the lower speed limit, 4 of our 60 cases would be disqualified because of slow speed of accommodation, the two qualified cases already discussed and two others which were disqualified by the eye examination. Both of these latter two had defective depth perception, and one had visual acuity of less than 20/20 as well. From Goodall's group this limit would disqualify 6 cases, 4 of whom were fliers.

If the limit were made 1.90 seconds, two more of our cases would be disqualified, making a total of 6. But these two cases were also disqualified by the eye examination, one because of defective visual acuity, depth perception, muscle balance, angle of convergence, and refraction; the other because of sub-normal visual acuity. Turning to Goodall's data, we find that this limit would eliminate 7 of his cases, 5 fliers, whose number of flying hours ranges from 90 to 250.

CONCLUSIONS.

1. While this method of testing speed of accommodation is satisfactory in determining the actual speed, unquestionably it is also a test, to a certain extent, of immediate memory. Many of the subjects complained that they could not remember the sequence in which the letters disappeared, although they felt confident that they had seen all the letters correctly.

2. The apparatus in its present form is cumbersome and the intricacies of operating it are too numerous to make it feasible for use in a routine examination. Another drawback to its use is found in the fact that a large number of subjects seem to find difficulty in adapting themselves to this particular test situation and require a long practice period before they can make a correct report of all three test letters. In certain cases, however, it might be used advantageously.

3. While most of the subjects of this series were nonfliers, the results obtained on them do not justify the conclusion that fliers (Goodall's group) possess a materially faster speed of accommodation than nonfliers.

4. While the theoretical importance of the speed of accommodation is recognized, it is believed that those possessing a degree of speed of accommodation which might endanger their flying, possess other deficiences which can be more easily detected. A possible exception might be found in cases where presbyopia has begun. Since the other tests disqualify the majority of cases with slow speed of accommodation, it is not necessary to establish a disqualifying limit for speed of accommodation. On the other hand, this test could not supplant the routine examination, as a number of disqualified candidates showed better than average speed of accommodation.

5. According to the observations of one or two fliers, this test as given, places much greater strain on the eyes than is required in any flying situation. This is undoubtedly true, since the figures on the dials of the plane are farther away and subtend a larger visual angle than the near E's used in the test. If this test were to be adopted as a routine test, it would be better to establish standards using larger test type, thereby more nearly duplicating flying conditions.

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MONOCULAR AND BINOCULAR JUDGMENT OF DISTANCE.

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The material for this article was obtained by Capt. Bascom H. Palmer, Medical Corps, ophthalmologist at the Medical Research Laboratory, Mitchel Field, N. Y., from the examination of 100 subjects comprising airplane pilots and officers and men of other branches of the service. His problem was to investigate the quality of depth perception judgment, as measured by the depth perception apparatus, and compare the judgments made with monocular and binocular vision. The following data were complete for each subject: (1) Ten judgments of depth perception (measured in millimeters) using binocular vision; (2) 10 judgments using the right eye only; (3) 10 judgments using the left eye only; (4) the visual acuity for each eye, tested by the Snellen test types; and (5) the angle of convergence. In each case it was noted whether the sighting eye was right or left.

The subjects were given the standard examination for flying and were rated qualified or disqualified on the findings of the examiner.

For measuring visual acuity the regulation Snellen test charts were used, the examinee occupying a chair 20 feet away from the wall upon which the charts were arranged. To qualify on this test the subject must have a visual acuity of 20/20 for each eye. The instrument with which the judgments of depth perception are made is known as the depth perception apparatus. It may be described as the front, back, and floor of a rectangular box, the sides and top of which are open. The floor is 21¾ inches from front to back and 13¾ inches wide, and the height of the back and front is 11½ inches. In the front is cut a window whose lower margin is 4 inches from the floor and whose outer margin is 2¾ inches from the side of the apparatus. The entire apparatus is painted a dull black and the anterior surface of the back covered with a square of dead-white cardboard.

From front to back of the floor of the apparatus runs a scale ruled off into centimeters and divided into millimeters. Beginning at the front end of the box the scale is numbered from 500 mm. up to 1,450 mm. A dead-black rod 6 inches high and three-eighths inch in diameter is placed in a stationary position at the point on the scale marked 1,000, and a second rod, identical in size with the first, sliding in a groove which runs the length of the box, may be set at any point on the scale by means of adjustable pulleys. The apparatus is placed directly before and beneath the Snellen charts and illumination is provided for both by one 200-watt daylight Mazda lamp, with an angle reflector installed about 4 feet above and in front of the test charts.

The applicant is seated 6 meters from the stationary rod in the apparatus. He is first given the opportunity of seeing the rods in the same plane, then by means of lines attached to the pulleys attempts to bring the adjustable rod in the same plane with the stationary rod after the rods have been widely separated by the examiner. The test is repeated 10 times, the subject's estimations of depth difference being read in millimeters directly from the scale.

Care is taken by the examiner to avoid casting a shadow on the background and to avoid giving the subject any indication as to whether he is doing poorly or well. In order to prevent motion parallax the applicant should also be instructed to hold his head straight. An average depth perception of more than 30 mm. disqualifies the subject.

Depth perception or judgment of distance is important in aviation in the making of landings, where the pilot must accurately judge his distance from the ground, trees, buildings, etc.; in low flying for the same reasons; and in formation flying, where he must keep a safe but short distance from other ships.

Regarding the factors operative in judgment of distance, there are some factors common to both monocular and binocular vision, such as terrestrial association, motion parallax, and aerial perspective, which are eliminated under test conditions. Accommodation and convergence can also be eliminated. Capt. H. J. Howard, in an article called "A Test for the Judgment of Distance," in the Transcriptions of the American Ophthalmological Society, 1919, says:

"The two remaining factors are the binocular parallax and the size of the retinal image. It is possible to obtain the relative values of these two factors by using the same test apparatus, first with two eyes and then with only one eye. In the first instance both factors may operate together; in the second instance the binocular parallax is eliminated and only the size of the retinal image can operate. This latter is practically as important a factor with one eye as it is with two. If by comparison it be found on the one hand that the results are the same or approximately the same, it is obvious that the size of the retinal image which operated in both tests is the important factor. If, on the other hand, it be found that the binocular test produces a far more delicate discrimination than the monocular, we are forced to the conclusion that the binocular parallax is the more important factor, and the size of the retinal image is negligible or practically so."

Bearing these facts in mind, we turn to the results of the depth perception tests. By averaging the ten readings for the right eye, the individual average for each subject was obtained. The same procedure was followed with the

readings for the left eye and for both eyes, and these averages were used in the calculations. The depth perception (D. P.) averages of all subjects were found to be as follows:

100 cases.	M (DP).	PEm.	Sigma.	C.
Right eye	118.30	±3.92	58.18	0.48
Left eye	118.50	±4.55	67.42	.47
Both eyes	18.65	±1.57	23.23	1.24
Sighting eye (right, 71 cases; left, 29 cases)	110.52	±4.19	62.12	.56

The great discrepancy between the average for both eyes and the average for either eye alone will be noted at once. The average judgment with the left eye is more than six times as large as the average for both eyes, and the averages for the right eye and the sighting eye are nearly as large. The mean judgments with the right and left eyes are very close, the average for the sighting eye being slightly better.

The probable error of the mean (PEm) gives the measure of unreliability of the mean and may be defined as that variation from the average which is as often exceeded as fallen short of. It is that amount which added to or subtracted from the mean gives a range within which 50 per cent of the values will fall.

Sigma is likewise a measure of variability. If on the probability curve a distance equal to sigma is laid off on either side of the mean and ordinates erected from the base line to the curve, two-thirds of the total number of measures will be found to fall in the area between the ordinates, base line, and curve. The large sigmas in this case (in one instance as large as half the distance estimated) indicate that the probable error of an individual estimate is large, and that the distribution is scattered—a large number of judgments falling wide of the average.

The variability of the different series of measurements may be directly compared by comparing their coefficients of variability (C). These coefficients indicate that the individual judgments made with the sighting eye and with the left eye are equally variable and are more variable than the judgments made with the right eye, while the judgments made with both eyes vary more widely than any of the others.

From a survey of these results it is plain, then, that in spite of the wide individual variations in judgment made with binocular vision, the average is far below that made with monocular vision.

The data were next rearranged according to the degree of visual acuity of the subjects. The average depth perception of those subjects having a visual acuity of 20/20 with each eye was obtained, and also of those subjects having a visual acuity of 20/15 with each eye. A similar average for both right and left eye was made for those subjects with a visual acuity of 20/20 and 20/15 respectively. The results of both groups are presented here for comparison.

	Cases.	M (DP)	PEm.	M dif.	Ped.	C.
Right eye 20/20	29	129.68	± 7.91	27.34	± 6.33	.48
20/15	60	102.34	± 4.74			.53
Left eye 20/20	18	151.94	±13.70	40.12	±12.78	.55
20/15	64	111.82	± 4.93			.52
Both eyes 20/20	16	28.11	± 1.96	16.09	± 1.74	.64
20/15	57	12.02	± .90			.83
All others	26	26.92	± 3.81	.....	.....	.....

One striking fact brought out by this table is that there were approximately three times as many subjects with 20/15 vision, or better, as with 20/20, although the latter is considered normal. It must be remembered, however, that the great majority examined were young men, the group average being 28.9 years. Those individuals with 20/15 vision were also better in judgments of depth perception than were the subjects having 20/20 vision, although the variability is about the same for each series of measurements. Particularly in the series for the left eye and for both eyes is this difference noticeable, indicating that the keener the vision, the more accurate would depth perception judgments tend to be. A correlation between these two factors of depth perception and visual acuity gave a result of 0.457 ± 0.053, a figure which is more than eight times its probable error and therefore a reliable indication that there is a definite relationship between the two and that improvement in the former is associated with improvement in the latter. After applying Chauvenet's criterion to eliminate the extreme cases which were not typical of the group, the mean of depth perception was found to be 16.27 ± 1.02, which is lower than the average formerly obtained for all cases, and the mean of visual acuity was 20/15+1, which is a high average. Inasmuch, then, as more than two-thirds of the subjects possessed a visual acuity considerably above the requirements demanded, it is evident that the degree of visual acuity considered a necessity for fliers is not excessive for the material available.

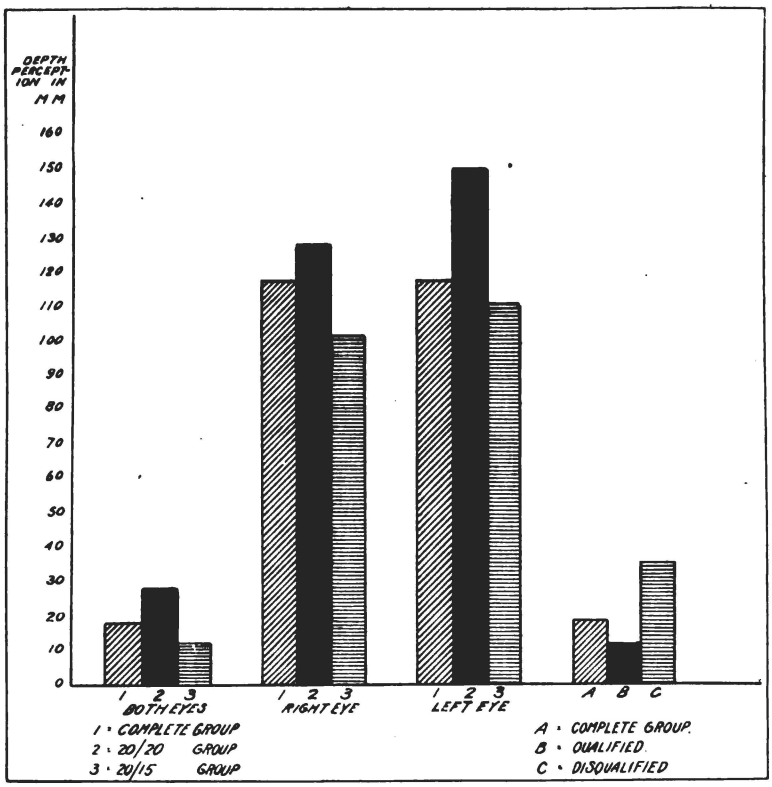
The fact that one mean is higher than another does not necessarily indicate a true difference between the means. A glance at the table of comparison shows that this difference is considerable, but the degree of reliability of that difference is determined by the size of the probable error of the difference (PEd). To determine a satisfactory degree of reliability, the difference of the means should exceed the probable error of the difference by at least three times, so it is apparent that the probable error of the difference of the means for both eyes (16.09 ± 1.74) is particularly significant, as the difference of the means exceeds it by more than nine times.

The subjects were next divided into two groups, (1) those qualified to fly and (2) those disqualified because of poor visual acuity, low angle of convergence, muscle imbalance, color blindness, etc. The average depth perception judgments for each group were obtained and they were found to differ widely. The mean in millimeters for the qualified group was 11.93 ± 0.52 with a coefficient of variability of 0.54 and the average for the disqualified group was 36.30 ± 5.72 and a coefficient of variability of 1.28. As more than 30 mm. disqualifies in the depth perception test, the size of the latter average is significant. After eliminating one extreme case in this group, the average is still 29.66 mm. The results show that the subject disqualified on any ophthalmological findings is apt to have a depth perception average near the disqualifying limit and to make erratic judgments varying widely from the normal average. The qualified man, on the contrary, has an average depth perception far better than the standard requirements, and his judgments are more constant and reliable.

Of the thirty disqualified subjects, nine failed to attain the required average of 30 mm. in depth perception, but in only one of the nine cases was the failure of depth per-

ception the sole disqualifying factor. The remaining twenty-one subjects had a qualifying depth perception average but were disqualified for other causes such as paralysis of the eye muscles, poor visual acuity, more than the allowable amount of hyperphoria or esophoria in conjunction with diplopia, etc. The fact that the mean for all thirty subjects is outside the qualifying limit, and even excluding one extreme case is 29.66 mm., shows that the readings in the majority of cases are very close to the disqualifying mark. The results indicate also that inability to judge depth perception distance with a normal degree of accuracy is quite closely associated with faulty ocular function.

the all-important factor in depth perception judgment, and that the size of the retinal image which operates in monocular vision is of practically negligible importance in judgment of distance. It is plain that for accurate depth perception judgment good binocular vision is necessary, and the results of these tests show that the better the visual acuity the more exact the depth perception judgment tends to be. As the average—with both eyes—for all subjects, both qualified and disqualified, is 18.65 millimeters, it would seem that the standard which designates 30 millimeters as a minimum depth perception requirement is not too high. On the contrary, from a consideration of the average for the complete group and for



The average angle of convergence for all subjects was found to be 58.9° ±0.98, and an attempt was made to discover a possible relationship between this angle of convergence and the diopters of accommodation of the right and left eyes, but as some of the necessary data were lacking in many cases the results were wholly unreliable. This outcome was not altogether unexpected, as the readings were all taken at 20 feet.

A graphic representation of the comparison of the averages of the depth perception judgments of the two groups of subjects based upon their degree of visual acuity with the average for the complete group is presented above. The great difference in judgments of depth perception made with binocular and with monocular vision would tend to prove that it is the binocular parallax which is the qualified group, which is 11.93 millimeters, it is probable that the standard should be raised and a minimum depth perception average of 25 millimeters or 20 millimeters be required.

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—By courtesy of the American Journal of Ophthalmology.

STUDIES ON THE RESPONSES OF THE CIRCULATION TO LOW OXYGEN TENSION.

V. STAGES IN THE LOSS OF FUNCTION OF THE RHYTHM PRODUCING AND THE CONDUCTON TISSUE OF THE HUMAN HEART DURING ANOXEMIA.

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[Figures in parentheses refer to bibliography at end of article.]

That systemic asphyxiation is a factor in producing slowing of the heart rhythm and in decreasing conductivity has long been known (Klug (1), Konow and Stenbeck (2), and numerous later investigators). Our present views as to the anatomical differentiations within the heart have resulted from a series of papers presenting the morphological and physiological facts of the conducting and nodal system (Kent (3), His (4), Keith and Flack (5), DeWitt (6), Mall (7), Lhamon (8), Eyster and Meek (9), and many others). The facts of the functional control of the heart rhythm and sequence from dominant centers as understood at the present time have been developed especially by Erlanger (10), Keith and Flack (5), Adam (11), Flack (12), Lewis (13), Ganter and Zahn (14), Meek and Eyster (15), and Lewis (16). The influence of temperature, of asphyxia, of drugs, and especially of the extrinsic nerves on the sino-auricular and auriculo-ventricular rhythms and on conduction have been discussed in several of the preceding references and also by McWilliam (17), Lewis and Mathison (18), Mathison (19), Meek and Eyster (20), Eyster and Meek (21), Schlomovitz, Eyster, and Meek (22), and by Lewis, White, and Meakins (23). The reference list is not exhaustive, but the literature is fully reviewed in several of the references given. We have also briefly reviewed the literature on asphyxia in Article III of this series (24).

The electrocardiographic method has been applied to the study of the changes in the mammalian heart in numerous studies from the laboratories of the University of Wisconsin by Eyster and Meek, who used also the method of asphyxia to follow the point of origin of the pace-maker of the dying mammalian heart. In Lewis's laboratory in London, too, numerous electrocardiographic studies have tended to clarify our knowledge of the physiology both of the factors of intrinsic and extrinsic cardiac regulative control. Lewis and Mathison (18) showed that conduction and rhythm production are decreased even to the point of suspension when an animal with open chest is allowed to asphyxiate by stopping artificial respiration, and they have published electrocardiograms showing these points. Ganter and Zahn (14) and Meek and Eyster (21) found that if the sino-auricular node was cooled locally the pacemaker was driven to a lower point in the heart, i. e., the auriculo-ventricular node. This the latter proved by two leads taken directly from the exposed heart. Lewis, White, and Meakins (23) showed that the displacement was by gradual steps in some animals (the cat) and by sudden shifts in others (the dog) as shown by shortening of the P–R interval. They observed that when the rhythm arises in the A-V node the conduction may be retrograde, as indicated by the R–P interval, a new point in mammalian heart physiology. Further asphyxiation suppressed the retrograde conduction and all evidence of auricular contractions disappeared. We call attention to the experiment of Lewis, Meakins, and White on the cat, Figure 6, Plate 2, with the following legend: "After establishing A–V rhythm by applying cold continuously, a cat was asphyxiated; by the one hundred and forty-fifth second of asphyxia the heart passed through several stages of partial reversed block and finally the auricular contractions had vanished. The curve commences at this state and shows the recovery of the S–A node soon after the withdrawal of cold from it. The ventricular rate is practically unaltered and complete heart block is evidenced by the dissociation of auricular and ventricular rhythms." This figure is quoted as direct experimental proof of asphyxial suppression of auricular contractions in the mammalian heart.

In our previous papers we have shown that in men during extreme oxygen-want very marked changes may occur in the mechanism of the human heart. These critical changes for the most part did not appear until the stage of oxygen-want in which the oxygen is insufficient to maintain the nervous system in conscious activity. In other words, the more profound changes during low oxygen are imminent at the approach of unconsciousness, and of skeletal muscular collapse, though cardiac slowing and disturbance of the normal mechanism follow these events in sequence. We have published examples in which two of the chief irregularities of the human heart are loss of auricular contraction as evidenced by disappearance of the P wave, and loss of internodal conduction as indicated by dissociation. In the present paper we give in detail the reactions of an extreme case of this type, a case somewhat different but crucial as regards the nature and sequence of the local cardiac changes which we have followed without interruption.

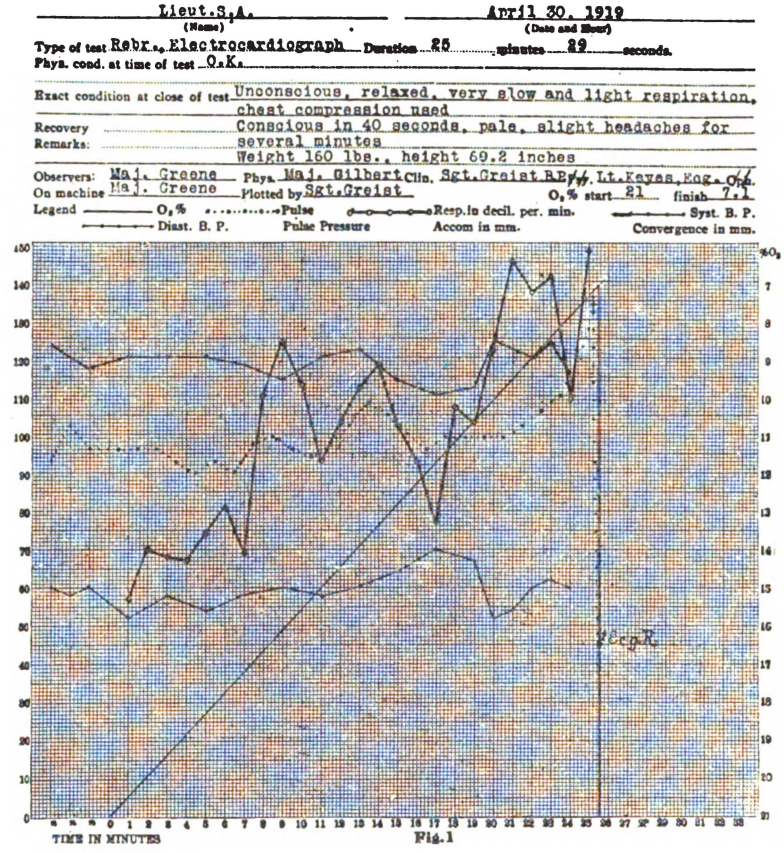

FIG. 1.—The clinical chart of Lieut. S. A. shows the heart rate, dotted line; systolic blood pressure, the top light line; diastolic blood pressure, the bottom line; respiratory minute-volumes, heavy line. The heart rates are taken by 20-seconds counts at the wrist during the first 20 minutes, and from the electrocardiogram from the 20th minute to the end of the record. The blood pressures are measured by the Rogers sphygmomanometer. The deciliters of air breathed per minute were read off the Larsen recorder. The blood pressure, heart rate, and deciliters of air are all shown by the legend to the left; oxygen percentages are indicated to the right.

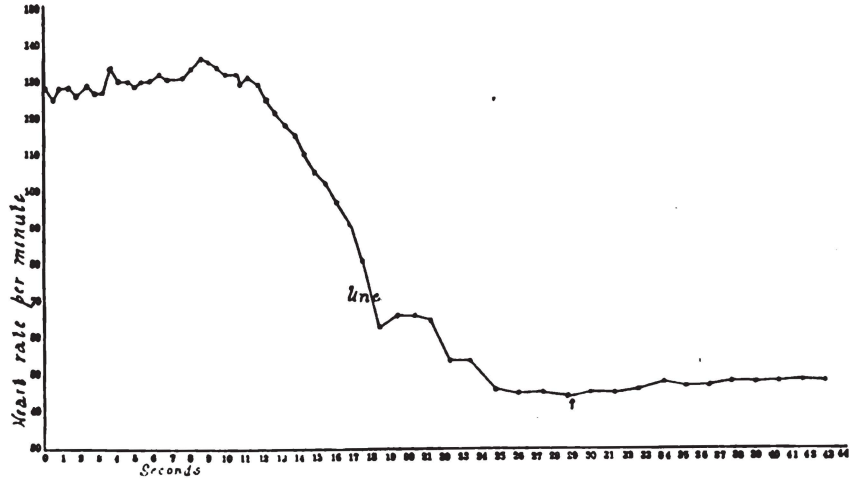

FIG. 2.—The heart rate per minute of Lieut. S. A. during the post-crisis stage of oxygen-want, calculated beat by beat, beginning with the 26th minute. *Unc*, became unconscious at about this point; *off*, removed from the test.

TABLE 1.—*Showing the variation in the pulse and in the electrocardiogram at intervals through the rebreather test. Time in seconds. Amplitude of the deflection in millimeters, equivalent to 10^{-4} millivolts. Lieut. S. A. April 30, 1919. Final oxygen 7.1 per cent. Time of run 25 minutes, 29 seconds. Equivalent altitude 28,000 feet.*

Trace and pulse number.	Time in minutes.	Oxygen in per cent.	Duration in seconds.			Amplitude in millimeters.				
			R-R.	P-R.	R-T.	P.	Q.	R.	S.	T.
1-10	Normal.	21.0	0.656	0.136	0.320	0.8	None.	14.0	1.0	2.4
2-4	5	18.2	0.648	0.140	0.328	1.0	None.	13.5	1.2	2.3
3-2	10	15.5	0.624	0.140	0.292	0.9	None.	15.0	1.6	1.8
4-1	15	12.7	0.640	0.152	0.312	0.9	None.	13.0	1.4	1.8
5-20	20	10.0	0.584	0.144	0.280	1.0	None.	12.0	1.5	1.6
6-122	22	9.0	0.700	0.152	0.296	1.0	None.	11.5	1.0	1.8
7-237	24	7.9	0.568	0.136	0.280	0.9	None.	12.0	1.4	1.0
8-275	25	[1]7.3	0.492	0.120	0.260	1.2	None.	9.5	1.4	1.0

[1] Circulatory break at the end, see Table 2. No recovery tracing secured.

TABLE 2.—*Variation in heart rate and in the electrocardiograms through the entire post-crisis stage of Lieut. S. A. The rates are computed on the basis of the length of the R–R intervals beginning at the crest of the maximum heart rate. The break occurred at 25 minutes, 10 seconds. The measurements of the P–R and R–T intervals are difficult and the factor of error is large. Lieut. S. A. April 30, 1919. Time of run 25 minutes 29 seconds. Final oxygen 7.1 per cent—28,000 feet elevation.*

Time in seconds beginning at 25 minutes.	Equivalent rate for each consecutive beat.		Electrocardiograms.			Remarks.
	Pulse number.	Rate.	P-R interval.	R-T interval.	R amplitude.	
10.00	1	132	0.13	0.26	11.5	
10.48	2	132	.13	.26	12.6	
10.90	3	129	.13	.26	12.4	
11.38	4	131	.13	.25	12.4	
11.84	5	129	.13	.27	12.6	
12.32	6	125	.13	.28	12.6	
12.80	7	121	.13	.29	13.0	
13.30	8	118	.13	.30	13.0	
13.32	9	116	.14	.31	12.4	
14.36	10	110	.13	.29	13.8	
14.96	11	105	.12	.30	14.0	
15.54	12	102	.13	.32	14.5	Muscular tremors severe during four beats.
16.12	13	97	.14	—	14.0	
16.80	14	91	.13	.33	13.4	
17.54	15	81	.12	.33	13.4	
18.48	16	63	.112	.33	13.0	P inverted.
19.36	17	66	.098	.31	13.6	Do.
20.28	18	66	.094	.30	13.0	Do.
21.18	19	65	.10	.30	14.6	Do.
22.30	20	54	.10	.34	14.0	Do.
23.40	21	54	.10	.30	16.0	Do.
24.68	22	46	.10	.31	16.0	Do.
26.04	23	45	.17	.35	22.6	R–P or reversed conduction
27.36	24	45	.21	.33	22.3	the P still inverted.
28.72	25	44	.23	.34	21.5	"Off" here.
30.04	26	45	None.	?	18.4	No P waves during the 10 re-
31.26	27	45	None.	?	16.5	corded beats of this stage.
32.68	28	46	None.	?	19.0	
34.00	29	48	None.	?	18.0	
35.28	30	47	None.	?	19.4	
36.58	31	47	None.	?	18.0	
37.82	32	48	None.	?	16.5	

Lieut. S. A. was carried to the stage of unconsciousness in an altitude test by the rebreather method, the procedure being the same as used in our previous research. Electrocardiograms were obtained at 5-minute intervals to 20 minutes, then a continuous electrocardiogram was recorded for the last 6 minutes and to the close of the test. The graph representing clinical progress of the entire test is shown in Figure 1. The general electrocardiographic changes throughout the test are given in Table 1. The heart rates calculated on the basis of the time of the successive cycles from a moment before the maximum heart rate through the terminal fall in rate to the end of the test are shown in Figure 2. The electrocardiographic data for the critical post-crisis period is presented in Table 2. The electrocardiograms representing the successive stages of the test are reproduced in Plate 1, Figures 1 to 8.

The general changes during the development of low oxygen are not essentially different from the types previously described. Lieut. S. A. follows the rule during the precrisis stage, both in the clinical cardio-vascular responses and in the changes shown by the electrocardiograms. The heart accelerated to 136 at the crisis, but with considerable variation in time of cycles between the twelfth and seventeenth minutes. The systolic pressure fell during the thirteenth to eighteenth minutes, which, taken with the rise in diastolic pressure, the change in heart rate and the fall in respiratory volume, indicates a failure to adequately respond to the strain at this period. He rallied and continued to compensate until the twenty-third minute and became unconscious in the twenty-fifth minute. These irregularities of compensation characterize nervousness during the test rather than weakness under the test. However, the test was made to the extreme limits and thus revealed vital and illuminating post-crisis changes in the heart.

Unconsciousness supervened at the point marked *Unc* in the electrocardiographic record, Figure 8. He was continued in the test until his muscles began to relax, i. e., 10 seconds after the evidence of unconsciousness, and was then rapidly removed from the rebreather. Skeletal muscle relaxation became complete during the removal of the mouthpiece, and relaxation continued to the end of the cardiographic record. His respirations at this time were very shallow and faint. Artificial respiration by compression of the thorax was produced at this point. Unfortunately at this critical time the electrocardiographic apparatus became disconnected so that the transitional stages toward cardiac recovery were not recorded. He remained unconscious about 40 seconds, then quickly and suddenly regained consciousness and muscular control. He was a little pale, was not nauseated, suffered some slight headache for several minutes, but otherwise showed no deleterious aftereffects from the experience.

Both the clinical determinations and the heart rates obtained from the electrocardiograms show early progressive acceleration of the heart. This reaction is usually given by a normal compensator during the early and precrisis stages of the altitude test. The heart rate augmented from the rather high initial rate of 90 to a maximum of 136 per minute at the crisis at the beginning of the twenty-fifth minute. At this time the rate began to decrease, at first slowly through 6 or 7 beats, then very rapidly until the low rate of 44 per minute was reached when the test was terminated. The beats remained at the slow rate for the remaining 10 seconds recorded.

The electrocardiogram taken continuously from the twentieth minute, therefore including the time from the moment of maximum heart rate through the entire terminal or postcrisis period, shows in continuous panorama the facts on which we base the interpretation of the

extreme effects of low oxygen on the behavior of the normal human heart. We emphasize above all the eivdence that oxygen deficiency does not become vital to the heart itself until late, certainly not before the onset of unconsciousness. But when the crisis is reached the postcrisis changes occur rapidly, indeed in a few seconds.

The graph, Figure 2, and the electrocardiogram, figures 8 and 9 of plate I, show that during 20 consecutive beats the rate dropped from 136 to 44 per minute. The rate was 100 at the beginning of a group of 4 contractions complicated in the electrocardiographic record by skeletal muscular tremors. Unconsciousness occurred during this period, according to the clinical evidence on which we base judgment. Lieut. S. A. did not immediately lose reflex contol of his muscles, and still held the mouthpiece safely for a few seconds longer. The rate was 81 at the inversion of the P and the onset of unconsciousness and 66 at its consummation.

observed by Ganton and Zahn, and by Meek and Eyster. The inverted P exists through seven successive contractions, though the third contraction does not show the phenomenon clearly. In these seven beats the P wave precedes the R by a very uniform but shortened time interval.

On the third beat before the close of the test the P wave suddenly shifts to a post R position with a relatively long R-P interval. The last beat of the three in which this condition exists occurs at the moment of taking "off." Each successive R-P interval is longer, 0.17, 0.21, and 0.28 second, signifying the progressive and rapid loss of reverse conduction. This group of contractions indicates the shift of the rhythmic center to a still lower or third point of origin, presumably low in the A-V node. The sequence is reversed and condution is back to the auricle. At this moment the rate is at its slowest—i. e., 44 to 45 per minute—where it remains with little variation during the last 10 beats recorded.

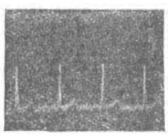

FIG. 1.
Normal, pure air.

FIG. 2.
18.2 oxygen.

FIG. 3.
15.5 oxygen.

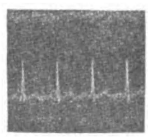

FIG. 4.
12.7 oxygen.

FIG. 5.
10.0 oxygen.

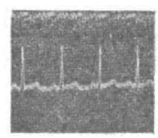

FIG. 6.
8.9 oxygen.

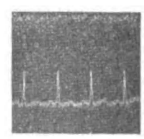

FIG. 7.
7.8 oxygen.

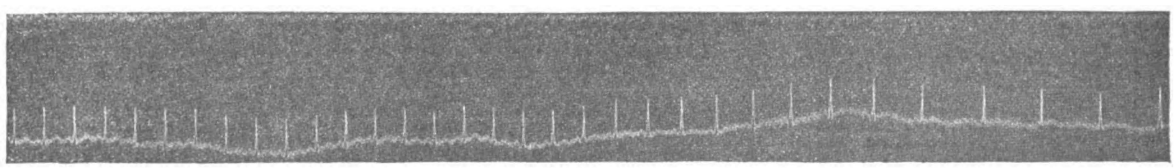

FIG. 8.—7.2 oxygen.

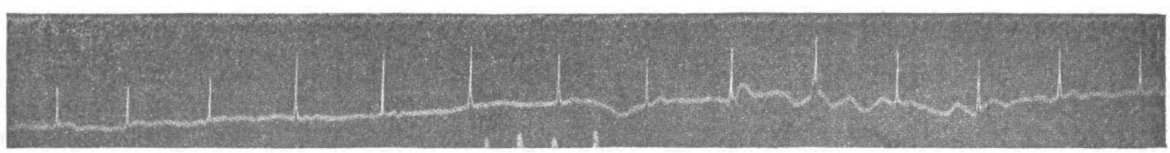

FIG. 9.—Continuation of figure 8.

PLATE I.—Responses to circulation of low oxygen test.

PLATE I.—The electrocardiogram of Lieut. S. A.; Figure 1, normal; Figure 2, after 5 minutes; Figure 3, 10 minutes; Figure 4, 15 minutes; Figure 5, 20 minutes; Figure 6, 22 minutes; Figure 7, 24 minutes; Figure 8, begins at 26 minutes and 10 seconds; Figure 9, continuation of Figure 8. The four shadows on Figure 8 and the word *off* mark the point when Lieut. A. was taken off the test. The changes in heart rate in Figures 8 and 9 are shown graphically in text Figure 2. Time in fifth seconds. The R deflections of the original record have been strengthened by the engraver in reproducing the plate.

An inverted P wave appears during the last heart beat of the group in which skeletal muscular contractions occurred. This beat is coinicdent with a decided slowing in the rate, from 102 just preceding the unconscious stage to 64 during this beat. There is also a sudden reduction in the P-R interval showing that the time of conduction from the new source of the beat to the ventricular tissue is reduced, from 0.127 to 0.098 second. (See Table 2.) Inversion of the P wave and shortening of the P-R interval are interpreted as signifying origin of the rhythm lower down in the system—i. e., the S-A node—or at least as low as the coronary sinus portion of the A-V node, as indicated in certain displacements

Augmentation in the amplitude of the R wave takes place at the time when the P shifts to the post R position. We offer no obvious explanation for this fact other than that the ventricle beats first in sequence; i. e., is the primary activity. During the last 10 beats the amplitude of the R varies little or none from beat to beat. The irregularity of the record from extrinsic currents confuses the R-S-T amplitudes to a degree.

The steps in the transition of the P outlined above indicate the suppression of the successive pace making foci. The normal S-A node first succumbs during asphyxiation. The first ectopic rhythmic focus next ceases to function. There is finally left a rhythmic center well

down in the conducting system adequate to maintain rhythm. It is true the rhythm is at a greatly reduced rate, although the reduction is not so great as that often observed in pathological heart block.

At the moment of closing the experiment the P wave disappeared entirely. It did not reappear during the ten ventricular complexes of the remainder of the record. This we interpret as suppression of function of the conducting tissue sufficient to block conduction from the lower rhythmic center back to the auricle, demonstrating for man the additional new point that anoxemia blocks retrograde conduction from the ventricle toward the auricle during A-V rhythm. This was first shown to be true during systemic asphyxiation by the method of stopping respiration in lower animals, by Lewis, White, and Meakins, who of course were dealing with excess of carbon dioxide as well as lack of oxygen. All the remaining contractions are normal ventricular complexes of the type in which the beat arises in the conducting system rather than in the muscle. No ectopic beats occurred in this case.

There is only the merest suggestion of an increase in rhythm during the ten beats that occur without auricular beats; in fact the rate is slow and remarkably regular from the moment the first R-P interval occurs.

This record gives conclusive evidence from the human subject that the pace-making function in the heart is depressed and lost in the descending direction during anoxemia induced by the rebreather method. The evidence from mammalian experimental sources is confirmed for the human. The most sensitive parts of the conducting system are the S–A node and the internodal region. These are both rendered inactive by oxygen-want long before rhythm and conduction are lost in the A-V node and the peripheral parts of the system. We believe these changes are immediately due to vago-spasm. But whether one accepts the explanation of vagal stimulation or of direct asphyxial effects, it is obvious that when for any reason, either physiological or pathological, the S-A pace-making center ceases to function and the auricular or internodal paths cease to conduct, thus suppressing auricular contractions, then the basic rhythmic property of the A-V node still persists to control the contractions of the ventricle for a time until the crisis passes. This control proceeds from the A-V node over the ventricle, and the rate, though slow, is adequate for a circulation of considerable efficiency. These observations agree with the deductions made in our previous paper. They confirm for man the facts pointed out by Meek and Eyster (20) for the dog, i. e., that the heart is sensitive to extrinsic control in the descending direction and "that the specialized tissues of the heart exhibit from above downward progressively diminishing degrees of automaticity."

The case of Lieut. S. A. differs from the others reported by us in that the shift of the point of origin of the rhythm and the loss of internodal conduction is by relatively sudden steps, rather than by progressive displacement of the pace-maker and of conduction.

The facts observed in our case are clear-cut and definite and we recognize that the practical significance in aviation and in clinical medicine is definite and clear. The slowing of the rhythm, inversion of the sequence to ventricle-auricle beats, and finally the decrease and disappearance of auriculo-ventricular conduction are all changes perfectly characteristic of over activity of the vagus center. This human case might be explained on the basis of Mathicon's observations of mammalian asphyxial vago-spasm. Wilson has chown that the S-A node is particularly sensitive to vagal control in man both in the normal (26) and in the stimulative stage of the action of atropine (27). Vagus action not only changes auricular rate but lowers auricular intensity, as shown by decrease in amplitude of the P. Change in amplitude of the P was not observed in Lieut. S. A. The P was inverted—not the usual type of vagus effect. The ventricular rate is most constant. In view of the evidence of direct vagal inhibitory influence over the A-V nodal rhythm, the failure of further ventricular slowing during the extreme anoxemia needs explanation on the vago-spasm hypothesis. However, we believe that the vagus stimulation hypothesis offers the most convincing explanation and is confirmed by this human case.

In the meantime we have in progress comparative experiments on mammals based on the rebreather-electrocardiographic methods which we hope will throw further light on the nature of the final post-crisis reactions of progressive oxygen-want as observed in man.

In closing this paper we again emphasize the numerous parallels we have observed in the physiology of the normal nodal system of the human heart in comparison with the facts of cardiography established on experimental animals. We also emphasize the correspondence as between simple anoxemia and the symptom complex of asphyxial cessation of breathing when excess of carbon dioxide is added to anoxemia.

SUMMARY.

An additional and extreme case of oxygen deficiency on the normal human subject showing changes in the heart during a rebreather test is presented with continuous electrocardiograms through the crisis and post-crisis periods. The data show:

1. That reflex muscular control in the human may persist 6 to 8 seconds after loss of consciousness from anoxemia.

2. That sino-auricular rhythm is lost by steps; first to a lower point in the sino-auricular system; second, to a point nearer the base of the ventricle, presumably the auriculo-ventricular node.

3. That internodal conduction is finally lost, a brief stage of reversed conduction terminating in lengthening R-P intervals precedes total loss of conduction.

4. That the ventricular rhythm is very persistent and unexpectedly regular during the late postcrisis stage. In this case the equivalent rates are from 63 to 44, increasing to 48 per minute in 10 seconds after removal of the mouthpiece.

5. That in man lack of oxygen induces a series of changes in cardiac rhythm, in conduction and in suppression of auricular contractions quite parallel to similar phenomena established in experimental animals under general asphyxiation.

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STUDIES ON THE RESPONSES OF THE CIRCULATION TO LOW OXYGEN TENSION

VI. THE CAUSE OF THE CHANGES OBSERVED IN THE HEART DURING EXTREME ANOXEMIA[1]

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[Figures in parentheses refer to bibliography at end of articles.]

In our previous papers we have presented the changes that occur in the human during extreme anoxemia with especial reference to cardiac physiology. In our rebreather method the carbon dioxide is absorbed by shell caustic potash, hence there is no increase in carbon dioxide of the inclosed air during the augmentation of respiratory volume. In fact there may be a decrease in carbon dioxide due to the overventilation of the lungs with the consequent lowering of carbon dioxide tension in the body. Therefore, the gradual reduction of oxygen in the air breathed, hence in the lungs and body tissues, may be considered as the primary cause of the physiological changes observed. The condition is a true anoxemia. We have already reviewed at some length the literature of this subject, especially that developed in connection with the work of the Medical Research Laboratory of the Air Service (1), where we first began the investigation of this problem on man.

In preceding papers of this series (2) we described the late cardiac effects of anoxemia when the condition is pushed beyond the ordinary limits of the technical air service examination. What we have described as the post-crisis stage includes the changes observed in the circulatory system and especially in the heart after unconsciousness has occurred. These changes in the heart of man are summarized as follows:

1. Progressive suppression of the S-A rhythm in the descending direction to the vanishing point.
2. Establishment and persistence of the A-V rhythm with its characteristic slow and regular rate.
3. Decrease in conduction in the internodal region to the point of suppression.
4. Reversed rhythm and reversed internodal conduction.
5. Auricular pause after reversed conduction disappears.
6. These changes obey the laws of cardiac nervous control of rhythm and conduction, as outlined by Eyster and Meek.
7. Rapid recovery from all these disturbances (i.e., within a few seconds) when the man is allowed to breathe fresh air.

Most of these phenomena had been described in laboratory animals under the condition of systemic asphyxiation, but not in man. Eyster and Meek (3) especially have advocated the view that the phenomena are primarily due to vagospasm. Others, especially those working in Lewis's laboratory, have emphasized the fact that the asphyxial stress on the heart also acts directly on cardiac tissue. In all the earlier experiments on animals two factors are involved—oxygen want and carbon dioxide excess. Mathison (4) alone has tried to separate these factors by allowing his animals to breathe pure nitrogen, thus getting rid of the carbon dioxide by excessive ventilation. He concludes that "want of oxygen * * * alone is responsible for the production of block." He says also: "The heart block is undoubtedly due to the effect of want of oxygen on the cardiac tissues." Mathison describes stimulation of the cardio-inhibitory center, especially after chloroform, but he closes his article with the sentence: "Heart-block appears to be a regular occurrence during asphyxia in dogs in which the vagi are cut. When the vagi are intact, permanent cardiac inhibition frequently comes on before heart-block can appear."

These quotations summarize the most direct evidence bearing on our problem that we have been able to find. There is nothing in the literature that deals directly with man which furnishes an experimental basis for analyzing the mechanism involved in the observations which we have reported.

Lutz and Schneider (5) studied the responses of men breathing pure nitrogen from a Larsen spirometer supplied from a gas bag and exhaling into outside air. By this method they produced acute anoxemia in a few seconds. They obtained cardiac acceleration in from 5 to 55 seconds, "within 15 seconds in 60 per cent of the cases." While they obtained unconsciousness in certain tests they record no heart rates at this stage, in fact, resupplied air and studied the return phenomena before the extreme anoxemia with which we are concerned had appeared. For the purposes of our experiments such methods are too acute and do not allow full adjustment of the tissues to the external conditions. The same questions hold with this work as with that of Mathison on dogs.

[1] A grant in aid of this research was made from the Patton Research Fund of the Northwestern University for which appreciation is expressed.

We also express our obligations to Prof. Frank G. Becht for the many courtesies extended by the department of physiology, of the Northwestern University School of Medicine, and for generous personal assistance.

We have not tried extreme anoxemia during atropinization, in fact we have had some hesitation in using this, the only method available for answering the question whether anoxemia in man produces the observed cardiac changes by direct action on the heart and its intrinsic mechanisms, or by changes in the extrinsic nervous apparatus, i. e., primarily by vagospasm. We have interpreted our human results as due to the latter phenomenon. But we have not deemed it advisable to perform the crucial tests on man without further experimental data from lower animals.

In the present paper, dogs are used as experimental materials. A further attempt is made to determine observational facts on which to base an answer to the questions stated above.

METHOD.

Dogs have been used exclusively during this series of experiments. Anoxemia has been induced after chloretone anesthesia either alone or combined with ether. We have used the rebreather method, constructing an apparatus of small size suited to animals of about 7 to 10 kilos body weight. Changes in the general blood pressure have been measured by a mercury manometer, taking the pressure from the carotid artery. Respiratory rate was recorded by the movements of the spirometer, which also recorded, though with a low percentage of accuracy, the relative tidal volume. This apparatus records the progressive changes in volume of the inclosed air, thus giving a measure of the variations in rate and amount of oxygen consumed.

Electrocardiograms were taken at intervals of about four minutes beginning with the normal. A continuous electrocardiogram was taken from a late moment in the precrisis stage through the entire post-crisis stage and till the ending of the experiment by death of the animal, or by recovery following artificial respiration.

An analysis of the inclosed air in the rebreather chamber was made at the close of the experiment. The Haldane apparatus and method were used. The sample of air analyzed was taken from the inhalent tube, in the attempt to measure the composition of the air used by the animal at the last inhalation before respiratory failure. This doubtless gives a somewhat higher figure than the average gas content of the entire rebreather apparatus. It is recognized that the alveolar air oxygen tension is slightly lower than that found by analysis of the air from the intake tube.

Chloretone anesthesia was used to render the animal immobile. Three-tenths of a gram of chloretone in oil per kilo of body weight was injected into the abdominal cavity. Animals vary slightly in their sensitiveness to chloretone. Occasionally a second small injection was required to produce sufficiently deep anesthesia. The 0.3 gram per kilo dose, however, produces complete unconsciousness in about 10 minutes. Chloretone in excessive doses somewhat depresses the medullary centers, but the reactions of the animal to anoxemia are qualitatively normal. We have used ether anesthesia, also chloretone-ether, but we are confident that the use of chloretone alone is without error.

EXPERIMENTAL DATA.

Progressive anoxemia has been used on twenty-one animals, a total of 41 experimental tests, to determine the course of physiological events. After anoxemia is pushed to the stage of suppression of the respiratory movements there still remains a considerable interval during which artificial respiration quickly revives the animal. Revival permits several tests on the same dog. Since our primary purpose has been to determine the mechanism of the effects of anoxemia expressed by changes in the heart, we have made the tests in four groups: 1, with the vagi intact; 2, with both vagi cut; 3, after atropine; and 4, with the vagi cut at the moment when advanced responses are in progress in the heart.

ANOXEMIA WITH THE VAGI INTACT.

The dog under chloretone and with intact vagi gives a cycle of changes in response to progressive anoxemia that is characteristic and qualitatively constant. In all essential respects the physiological changes observed are very similar to those observed in man up to the stage when, in man, the tests are terminated. In the experiments recorded here the tests were carried to a much greater extreme. The changes observed in 16 experiments on intact animals which we stress are first, in the respiratory rate and tidal volume; second, the rate of oxygen consumption; third, the blood pressure; fourth, the heart rate and sequence.

THE RESPIRATORY RATE AND TIDAL VOLUME.

The changes in respiratory rate and volume during general asphyxia in man and animals have been presented in an extensive literature. The more recent papers that present aspects of anoxemial asphyxia are those from the experiments of Hough (6), Mathison (4), Gasser and Loevenhart (7), the reports of Lutz, Gregg, and Schneider (8), Ellis (9), Greene (10), from the Air Service data, and Haggard (11). The literature is more fully reviewed in these latter papers.

The experimental data concerning the respiratory responses of the dog to progressively induced low oxygen are in a manuscript in a paper by the senior author (12), but we abstract by permission from the summary of that paper:

"Chloretonized dogs during the rebreather test show the following panoramic changes in respiratory rate and amplitude. The sequence is more sure when the cycle is completed in from 15 to 18 minutes.

"1. There is little change in either the rate or amplitude of respirations in the early part of the anoxemial test, i. e., in the first 50 to 60 per cent of the duration of the test.

"2. The amplitude and tidal volume steadily increase during the last half of the test and until the respiratory crisis is reached.

"3. The respiratory rate also increases but becomes more and more irregular as the crisis is approached.

"4. The rate and amplitude both rapidly decrease during the post-crisis until within a few seconds all movement ceases.

"5. The rate of oxygen consumption was remarkably uniform to the approach of the crisis when it progressively decreased until all respirations ceased."

The dog endures a surprisingly low oxygen, as a glance at our tables will show. The average of all the acceptable tests is 3.26 per cent. The extremes vary from 4.9 to 1.6 per cent. The highest content of oxygen of air that supported respiratory movements in the dog is well below the limits that produce respiratory stress and failure in the few

extreme cases we obtained with men. Only one man of our series, Lieut. S. A. (13), certainly reached the limit of respiratory pause. His residual oxygen in the rebreather was 7.1 per cent. Others, in light of our more recent experiments on dogs, were undoubtedly just short of the point of respiratory failure when removed from the test. The evidence is found in the cardiographic records.

The rate of oxygen consumption, which of course varies with the size of the animal according to the surface area, is very uniform up to the moment of the onset of the respiratory crisis. From this point until the respirations cease the rate of oxygen consumption progressively diminishes. (See experiments 38 and 41, figs. 24 and 34.) Following the last respiration the base line usually falls somewhat in the record. (See experiment 38, fig. 23.) The explanation is that when the dog stops breathing the muscles relax and the chest volume decreases, forcing some of its alveolar air into the rebreather apparatus. When the respirations cease the tracheal tube is clamped off from the rebreather and the rebreather air then analyzed. The analyses therefore represent the percentage of oxygen in inspired air that just fails of maintaining respirations.

TABLE 1.—*Showing the entire group of experiments of the series. Chloretone anesthesia was produced by injecting a saturated warmed solution in oil into the peritoneal cavity. To the volume of air recorded for the rebreather must be added the volume of the dead space of the apparatus, about 1,100 cc., and the air of the respiratory passages. Carbon dioxide was not always perfectly absorbed in the earlier experiments.*

Date.	Experiment.	Dog.	Weight.	Chloretone per kilo.	Respirations stopped.	Air at beginning.	Air at end.	Oxygen reached.	CO_2.	Vagi cut or intact.	Electrocardiograms.
1920.			*Kgm.*	*Grams.*	′ ″	*Liters.*	*Liters.*	*Per cent.*	*Per cent.*		
May 20	1	1	.....	None.	.....	6.0	.....	.....	.....	Intact	No.
Do	1	1	.....	None.	15 00	6.0	[1] 3.37	2.44	.....	do	No.
May 21	3	1	.....	None.	10 00	5.0	.....	4.4	.....	do	No.
Do	4	2	.....	None.	.....	5.0	.....	6.1	.....	do	No.
May 22	5	1	.....	None.	14 00	6.0	[1] 3.75	2.7	0.02	do	No.
May 24	6	3	11.4	0.3	17 15	6.0	4.5	3.83	.....	do	No.
Do	7	3	11.4	.3	14 30	5.0	3.9	.....	.....	do	No.
Do	8	3	11.4	.3	17 00	5.0	3.87	3.62	.45	Cut	No.
May 25	9	5	.....	.3	21 50	5.0	3.9	3.82	.10	Intact	No.
Do	10	5	.....	.3	19 20	4.0	3.12	3.71	1.65	Cut	No.
Do	11	5	.....	.3	19 45	3.0	2.37	3.11	2.66	do	No.
May 26	12	6	20.0	.3	11 12	6.0	4.8	4.09	4.00	Intact	Yes.
May 27	13	7	13.0	.4	14 00	4.0	3.05	2.58	.68	do	Yes.
Do	14	7	13.0	.4	5 00	[2]	[2]	1.6	.09	Cut	No.
Do	15	7	13.0	.4	13 42	4.0	.....	4.06	1.5	do	No.
Do	16	7	13.0	.3	10 48	4.0	3.15	3.05	1.48	do	No.
May 28	17	8	11.4	[3] .2	13 00	4.0	3.15	2.59	1.63	Intact	Yes.
Do	18	8	11.4	[3] .2	12 15	3.0	.....	2.76	.93	do	Yes.
May 29	19	9	9.0	.3	15 20	4.0	3.25	4.46	.43	do	Yes.
Do	20	9	9.0	.3	.....	3.0	.....	4.44	Trace.	do	Yes.
June 4	22	11	10.0	.3	15 00	3.0	2.2	3.27	None.	do	Yes.
Do	23	11	10.0	.3	10 15	3.0	2.25	2.34	.....	Cut at crisis.	
Do	24	11	10.0	.3	[2]	[2]	.....	1.87	None.	Cut	Yes.
June 5	25	12	10.0	.3	14 15	4.0	3.05	5.02	1.04	Intact	Yes.
Do	26	12	10.0	.3	13 30	3.0	2.3	5.19	.46	do	Yes.
Do	27	12	10.0	.3	15 20	3.0	2.37	5.52	1.37	Cut	Yes.
Do	28	12	10.0	.3	16 05	3.0	2.3	.....	.....	do	Yes.
June 10	29	13	9.0	.3	14 00	3.0	2.07	2.2	None.	Intact	Yes.
Do	30	14	9.0	.3	8 20	3.0	2.2	4.27	.....	do	Yes.
Do	31	14	9.0	.3	7 30	4.0	3.22	5.46	.....	Atrop	Yes.
June 11	32	15	8.0	.3	15 30	3.0	2.2	4.17	Trace.	Intact	Yes.
June 12	33	16	7.5	.3	12 20	3.0	2.32	4.37	Trace.	do	Yes.
Do	34	17	10.0	[3] .3	16 15	4.0	3.05	2.94	Trace.	do	Yes.
Do	35	17	10.0	.3	13 42	3.5	2.65	2.87	None.	Cut	Yes.
June 14	36	18	10.0	[3] .3	10 25	3.5	2.42	3.46	Trace.	do	Yes.
Do	37	19	9.0	.3	18 30	3.5	2.5	2.43	.....	Intact	No.
Do	38	19	9.0	.3	14 30	3.0	2.2	2.38	.....	do	No.
Do	39	19	9.0	.3	[2]	[2]	.....	2.2	.....	do	No.
June 15	40	20	16.0	.3	8 54	4.0	3.25	2.5	.....	do	Yes.
Do	41	21	19.0	.3	11 00	4.0	2.92	1.8	.10	Cut	Yes.

[1] The trial face mask used probably leaked on expiration. [2] Short special test. [3] Ether.

EFFECTS OF ANOXEMIA ON BLOOD PRESSURE AND ON THE HEART RATE.

Both the blood pressure and the heart rate respond typically and with fair constancy to anoxemia. The rebreather method, with the taking up of carbon dioxide by the potash cartridge absorption, induces anoxemia so gradually and evenly that the conditions can be repeated with great accuracy. The experimental cycle of changes constantly recur with only very minor variations.

BLOOD PRESSURE CHANGES IN THE INTACT ANIMAL.

Blood pressure remains remarkably constant for the first half or two-thirds of a rebreather test on the dog. This is shown very well in experiment 38 with the vagi intact. In this test there was little or no change in the blood pressure for the first 10 minutes of a 16-minute experiment. Beginning at about 10 minutes, the blood pressure very slowly increased through 2 or more minutes, then more and more rapidly until the maximum was reached at the time of the vascular crisis. This crisis coincided very nearly with the respiratory crisis.

Sometimes the maximal blood pressure lags a few seconds after the respiratory failure. The absolute rise in blood pressure varies in different experiments. It may amount to as much as 40 or 50 per cent of the initial pressure. (See experiment 41.) Occasionally the rise in pressure is only slight. In all cases it occurs at the extreme stage of anoxemia. The rise in blood pressure is accompanied by an increase in pulse pressure. This change is never so great in the dog but that the diastolic phase, or minimal pressure, is as great or greater than the normal. In man

the diastolic pressure seldom increases to any appreciable degree during an official rebreather test, but it always falls rapidly near its close if the test reaches the limit of compensation.

Events occur very rapidly in the circulatory postcrisis. The salient events are progressive slowing of the heart and gradual lowering of blood pressure early in the collapse, followed by a rapid fall in both rate and pressure later. (See experiment 41.)

In the crisis and during the postcrisis stages blood pressure undergoes greater and more rapid variations. The rule is that the pressure very gradually falls during the postcrisis and until the respirations cease. The heart slows down during this phase and the pulse amplitudes increase. Consequently the diastolic pressure falls rapidly while the stysolic pressure is maintained or may even rise. The maximal systolic pressure of this cycle is usually not reached until 20 to 40 seconds after respirations cease. The pessure events just described are followed by progressive and rapid decrease of both systolic and diastolic pressures with decrease in pulse rates until the pulse can no longer be distinguished and the pressure remains constant at about 15 to 20 mm. Hg. The length of time required for the entire postcrisis cycle is from 3 to 5 or more minutes after respirations cease.

Simple artificial respiration or insufflation suffices quickly to resuscitate an animal during the time when the pulse is still distinguishable on the manometric record. Later than this additional measures must be employed. Recovery of both heart rate and blood pressure when they occur are prompt, i. e., within 10 or 15 seconds.

The comparison between our results and those obtained by the methods of rapid deprivation of oxygen as practiced by Mathison (4) and by Lutz and Schneider (5) is rendered difficult, because in such experiments the results are brought on by immediate and rapid asphyxiation, i. e., within a few seconds. Mathison produced asphyxiation in his animals by stopping artificial respiration, and by using nitrogen gas with or without a minimal amount of oxygen, 1 to 2 per cent. In either case the transition from normal air to the asphyxial condition is sharp and abrupt. Schneider and Lutz had men rebreathe nitrogen gas into a small bag. Our animals are allowed 10 to 18 minutes to gradually exhaust the oxygen from the air they rebreathe. There is adequate time for slow and gradual adaptation.

When natural respirations stop it can be assumed that the tissues are already deprived of their free oxygen. The low oxygen content of the last inhaled air is the basis of this deduction. In anoxemia there is not such an abrupt and violent response in blood pressure as was obtained by Mathison. On the other hand, the rise in blood pressure is very gradual, generally uniform, and passes away with the same progressive type of readjustment.

BLOOD PRESSURE CHANGES WHEN THE VAGI ARE CUT.

If anoxemia is induced after both vagi have been cut the blood pressure runs a course qualitatively very like that in the intact animal. The variations are chiefly those conditioned by changes in heart rate and pulse pressure. The detailed picture is as follows:

The average blood pressure does not vary during the early part of the test as much as in the intact animal. But as stress from oxygen-want becomes more acute the blood pressure rises as in the normal animal. The rise progressively increases to a maximum at the anoxemial crisis. Very little difference exists in either the rate of time of development of the crisis. The type change is shown in the last part of figure 34.

After respirations cease, sometimes a little earlier, the blood pressure slowly declines through 40 to 60 seconds. It then may show a slight increase, but finally falls rapidly through 2 or 3 minutes, then more slowly for 1 or 2 minutes more until the positive pressure of 15 to 20 millimeters Hg. is reached.

If both vagi are cut the anoxemial curve of the dog never shows the enormous variations of pulse pressure during the early post-crisis stages. The response is in sharp contrast with the responses when these nerves are intact. We have never obtained confirmation of the lowered but sustained blood pressure associated with the slow heart rate, large pulse amplitude and heart block as given for the cat with the vagi cut in Mathison's experiments (see his fig. 5) (4). In dogs with vagi cut the final stages of anoxemial heart block have never appeared until the pressure approached equilibrium and the heart beats were no longer recorded by the manometer.

CHANGES IN THE HEART RATE IN THE INTACT ANIMAL.

The heart rate is very uniform during the first 50 to 60 per cent of the anoxemial test. Unless stimuli from the outside occur, this regularity is uninterrupted. Sooner or later, varying somewhat with the animal, the heart rate slowly and gradually augments. This increase continues along with the increase in blood pressure previously described. Whether the increase in rate is the chief factor producing the rising pressure has not been determined in this investigation, but Mathison speaks of vasomotor stimuli in the spinal animal. In an experiment running 15 minutes the increase in rate will be very apparent by the tenth or eleventh minute. It will progressively augment to a maximum at 13 or 14 minutes. The maximum rate is associated with or slightly precedes the maximum blood pressure. This group of responses of maximal heart rate, crest of blood pressure, and slowing and stopping of respirations is the complex for which we use the term "crisis."

After the rise of blood pressure passes its crest and while the respirations are beginning to slow and oxygen consumption is obviously decreasing, the heart rate also begins to slow. The decrease in heart rate is very gradual at first but rapidly becomes increasingly slower until the maximum rate is cut to a half or a third. In experiment 41 the slowing was from 161 to 44 beats per minute in 70 seconds.

If an animal with intact vagi is allowed to continue in the anoxemial state then the heart rate remains slow after the blood pressure falls, often stops for a few seconds at a time, and ultimately ceases altogether. The electrocardiographic record shows that beats continue many seconds after the manometer fails to record pressure changes. It takes an average of 3 or more minutes to run this cycle of changes after respirations cease.

CHANGES IN THE HEART RATE WHEN THE VAGI ARE CUT AT THE BEGINNING OF THE TEST.

If the vagus nerves are cut before beginning the experiment, the heart rate is of course at a higher level. However, for the first 50 or 60 per cent of the duration of the experiment there is no other change in the character of the rate.

During the last third of the experiment, passing through the crisis as indicated by the maximal blood pressure and stopping of respirations, the heart rate augments in the pre-crisis period and continues at a rapid rate during the post-crisis. There is no early cardiac slowing to the extremely low rate observed when the vagus nerves are intact. The rate remains uniform and high for from one and one-half to two minutes after respirations stop and until the blood pressure is falling rapidly. By the moment the blood pressure has declined to one-half its earlier maximal the heart rate has become very evenly and gradually slower. It beats more and more feebly until it stops or until irregularities develop. When the heart is beating too feebly to produce any visible movement of the meniscus of the manometer the electrocardiograms show it to be still contracting in a normal sequential rhythm. It keeps this up for many seconds but ultimately block or independent auricular or ventricular beats are established and death follows.

The early cardiac slowing observed in dogs with intact vagi does not occur in our animals with vagi cut. Neither is there any evidence of change in conductivity, or block in the early phase of the post-crisis period. These come only three to five minutes later and are only revealed by the electrocardiograms.

CHANGES IN THE HEART RATE AND BLOOD PRESSURE AS INFLUENCED BY CUTTING THE VAGI AT THE MAXIMUM SLOWING OF THE EARLY POST-CRISIS PERIOD OF THE INTACT ANIMAL.

The discussion of the preceding topics clearly indicates that there are two critical times as revealed by the changes in heart rate during the post-crisis period. The first is at the time of cardiac slowing in the normal intact animal at or near the moment when respirations stop. The second is the cardiac slowing that comes 3 to 5 minutes later in an animal in which the vagi are cut at the beginning of the experiment.

If at the moment of maximum slowing of this early period the vagi are cut, then the whole situation is rapidly altered. The facts are revealed by close comparison of typical experiments—i.e., Nos. 38, 40, and 41. In these experiments we secured complete respiratory, circulatory, and, in 40 and 41, electrocardiographic records without interruption through the entire post-crisis period. The vagi were cut in succession when the heart rates had dropped to between 40 and 50 per minute.

In experiment 38 the rise of blood pressure at the crisis was moderate but the heart slowing came on rapidly, the rate dropping from 176 at the crisis to 76 and then to 48 per minute. The right vagus was cut first, at 15 minutes from the beginning of the test and 45 seconds after respirations stopped. There was a sudden but momentary rise in blood pressure and an increase to a heart rate of 88, figure 23.

The left vagus was cut 40 seconds after the right. The heart rate immediately increased to 172, then 216. The original maximal rate was 174. The blood pressure at once rose to the maximal systolic pressure during the preceding period of slow heart beats, then as rapidly fell through 10 seconds, and more slowly through the next 40 seconds. Artificial respiration was then established, and the animal promptly recovered.

Cutting the right vagus led to an increase of rate from 48 to 88. The high pulse pressure, however, continued. Cutting the second or left vagus released the heart at once to its maximum rate at the crisis. One can not escape the deduction that the extreme post-crisis slowing was a vagus phenomenon—i.e., vagal spasm—from which the heart was immediately released when the vagus nerves were cut.

Experiment 41 was also used to test the effect of cutting the vagus nerve during the early slowing in the post-crisis period. The maximal blood pressure was high in this experiment, about 50 per cent above the pre-crisis average. The heart rate slowed during the interval of 45 seconds between the maximum blood pressure and the stopping of respirations. The manometer failed to record a few beats near the moment of stopping of respirations, but this does not veil the fact of the rapid and progressive cardiac slowing up to the moment when the right vagus was cut 35 seconds after respirations ceased.

For five heart beats preceding the cutting of the right vagus nerve the rate was at its lowest, 35 per minute. After one or two irregular beats at the moment of cutting the heart remained very regular and strong at the rate of 44 per minute. This was adequate to maintain the pressure at a uniform level during the interval.

The left vagus was then cut with a minimum amount of manipulation. The heart rate immediately rose from 44 to 180 per minute. The blood pressure was momentarily increased but followed by a fall at first rapid, then more slowly, until no further heart beats could be shown in the record of the manometer. The rate was well sustained until the pressure became low. Then the rate, too, slowly declined just as in experiments when the vagi were cut at the beginning.

A continuous electrocardiographic record was maintained until no heart beats were visible by this means. The details obtained by this method are given later. No effort was made to resuscitate this animal.

SUMMARY FROM THE BLOOD PRESSURE RECORDS.

The blood pressure records alone seem to prove that there are two post-crisis periods of slowing of the heart rate in anoxemia, the first a function of the vagus center, vagospasm, and the second a direct effect of oxygen-want on the heart itself. The electrocardiograms complete the evidence. We may therefore summarize the observations from blood-pressure records obtained by carrying anoxemia to the complete limit of stopping respirations and heart beats.

1. The reactions of the respiratory center of the medulla become at first slow, then cease. When lack of oxygen is pushed to the death there is a phase during which the respiratory center does not receive enough oxygen to maintain its normal discharges. Finally it ceases physiological activity from true anoxemia.

2. The inhibitory centers controlling heart rate do not fail as early as the respiratory mechanisms. This is indicated by the appearance of the maximal cardiac slowing after the respiratory center has ceased.

3. The cardiac slowing in the early post-crisis stage is not due to cardiac failure, i. e., muscle and bundle failure, since it does not occur if both vagus nerves are previously cut.

4. Direct cardiac anoxemia is not adequate to suppress heart activity until from three to five minutes after respiratory failure.

5. The extreme slowing occurring after respiratory failure is promptly removed only after cutting both vagi. It is immaterial which nerve is cut first in so far as the gross rates are concerned, though differences exist in the behavior of the heart controlled by the right or the left vagus only.

6. The extreme slowing is due to vagospasm which suppresses S–A rhythm. It is not ordinarily adequate to suppress A–V rhythm until anoxemia approaches a direct fatal effect. This slow rate therefore is an A–V rhythm released by vagus inhibition of S–A rhythm under the stress of anoxemia.

7. In extreme anoxemia when the vagi are intact inhibition may suppress the A–V rhythm. But when it occurs, a rhythmic center develops in the bundle branch, as in experiment 26, figured in Plate I, figures 4 and 5.

8. Considering the heart itself, it is proven that there is an interval of from three to five minutes following respiratory failure during which cardiac beats are maintained. The rate becomes progressively slower and slower. At any moment during this interval a supply of fresh oxygen by artificial respiration is adequate promptly to recover circulatory and respiratory efficiency and remove the vagal inhibition.

9. What we have proven true for the dog checks so closely with our observations on man in the early stages of post-crisis anoxemia that we can not but believe that the mechanism of the reaction is the same in man and the dog in the final stages of progressive loss of respiratory and circulatory function.

10. It follows that in man asphyxiation by anoxemia has a considerable margin of safety provided only that a few whiffs of oxygen can be introduced into the lungs within the three to five minute intervals during which the heart continues to beat following respiratory collapse. This interval is critical and success does not always follow artificial respirations in the chloretonized dog when no other aid to resuscitation is used.

EVIDENCE FROM THE ELECTROCARDIOGRAMS.

The electrocardiograms presented in the plates are all taken with the lead II. The lead was from the right shoulder to the left leg. Small nickel-plated electrodes were inserted through a slit under the skin and stitched into place for the early tests, but later nickel-plated binding posts were screwed directly into the head of the right humerus and into the shaft of the left femur. This last method proved very satisfactory and most convenient.

The normal dog electrocardiograms most often obtained are illustrated in either of the three normals in Plate II, Figure 8, Plate IV, Figure 25, and Plate V, Figure 35. The R is very tall and the T negative or at best diphasic, as in Figure 35.

As anoxemia proceeds the most typical change is in the T wave. It becomes positive, then increasingly taller until at times the T is as tall as the original R. (Figs. 30 and 41.) The maximum T is usually obtained at and following that stage of anoxemia in which respirations have just ceased. Figures 41 and 42 illustrate the change in the amplitude in the R, which decreases, and the S and T, which both augment during extreme anoxemia following sectioning of the vagi and preceding complete cardiac anoxemial asphyxiation. This cyclic increase of the T running through the post-crisis was obtained over and over again. It apparently does not depend upon change in the position of the heart. The early experiments were performed with the animal lying on its back. But later the animal was turned to a 45° angle toward its left side. In this position the filled ventricle would tend to fall toward the left at all stages of the test.

The changes in the duration of the different phases of the electrocardiograms in the main coincide with those already described for man (1). With acceleration up to the crisis there is a perceptible shortening of both P–R and R–T intervals.

POST-CRISIS CHANGES IN THE ELECTROCARDIOGRAMS WHEN THE VAGI ARE INTACT.

At the onset of the anoxemial crisis the blood pressure passes its crest and the heart rate becomes gradually slower. Plate II, Figures 9 and 10, Plate IV, Figure 27, and Plate V, Figure 38, all show this early slowing. This stage occurs at or preceding the moment of the stopping of respirations. Progressive slowing continues until the rate drops to one-half or one-third the normal. During the slowing the T wave greatly increases without other profound change.

Often the rate suddenly shifts, as in Plate V, Figure 39, to a lower level, during which profound change in the type of electrocardiogram occurs. In experiment 41 the change came at the sixth complex of Figure 39. The five preceding complexes show progressively longer P–R intervals, showing delayed conduction, at the sixth and two succeeding complexes S–A rhythm disappears and A–V rhythm becomes established. In the sixth complex the P wave is superimposed on the positive limb of the T. In the seventh it succeeds the T. In both cases the internodal conduction is reversed, i. e., proceeds from the A–V node toward the auricle. However, conduction is sharply delayed in the seventh complex.

The same phenomenon is shown in Figure 11, Plate II. The shift to A–V rhythm occurred in the second complex and those succeeding as described in the protocol of this experiment, No. 29. In Plate I, Figure 2, A–V rhythm was established in the third complex and continued with reversed conduction through a series of 29 beats, the last of which is shown in Figure 3 of this plate.

In Plate III, Figure 19, a type of anoxemial influence is shown, undoubtedly of vagus origin, namely, a primary influence on the conducting bundle. A 2–1 block appeared for four groups with a progressive decrease in the P–R interval, signifying a simultaneous displacement of the rhythmic center toward the tail of the S–A node. In short, the vagus here produced its strongest effect on conduction but it also inhibited rhythm to a degree. Later in the course of the anoxemia internodal conduction was occasionally blocked and rhythm of both auricles and ventricles was enormously slowed.

The type of vagus action which drives the rhythmic center toward the tail of the S–A node is best shown in Figure 28, Plate IV. This figure illustrates one of a series of groups of such variations in which there was a periodic return of the normal P–R interval. (See protocol, experiment 40.)

The most extreme type of inhibitory displacement of rhythm is illustrated in Figures 3 and 4 of Plate I. After 49 consecutive beats arising in the A–V node the rhythmic focus suddenly shifts to a center in the left bundle branch, the second complex in Figure 3. This type continued for 10 complexes at a rate of 26 per minute. Recovery occurred promptly on admitting air, the last complex in Figure 4. The last complex in Figure 13, Plate III, experiment 29, also shows a rhythm proceeding from a center in the left bundle branch. In neither of these two unique cases did conduction reach the auricle.

No reference has been found in the literature to any instance of a rhythmic center so low in the bundle system. But Dr. Frank N. Wilson has very kindly sent us a very clear electrocardiogram showing displacement of the pacemaker of this class which he obtained in the dog quite incidental to other experiments.[2] "The animals were given large doses of morphine, and this sometimes produced marked inhibition. In this particular animal a center located in the left bundle branch escaped and transitional complexes of the type mentioned by you occurred. In this instance I think no alternative explanation is possible." By Doctor Wilson's permission, this additional evidence is presented in Figure 43, Plate VI. Eyster and Meek's conception that the vagus suppresses cardiac function in the descending direction is carried a step further by these two experiments than has previously been suspected.

ELECTROCARDIOGRAMS WHEN THE VAGI ARE CUT.

If the vagi are both cut at the beginning of an anoxemial test, then no irregularities of the electrocardiographic complex occur in the early post-crisis period. It has already been explained that under these circumstances the rate is not slowed until late in the post-crisis asphyxiation, from 3 to 5 minutes or longer. Although the heart rate ultimately becomes gradually slower and finally stops, or becomes irregular, there is a long series of perfectly normal complexes, a series that extends through the slow and irregular rates of the early post-crisis shown in Figures 1, 7, 18, 23, 24, and 34, and in the electrocardiograms of the corresponding stages. Release from these early irregularities is best shown in Plates IV and V, illustrating the effects of cutting the vagus nerves in succession during the early crisis.

ELECTROCARDIOGRAPHIC CHANGES WHEN THE VAGI ARE CUT DURING THE EARLY CRISIS.

In Plate IV, Figures 29 and 30, the vagi were cut in succession at the moments indicated. When the first nerve was cut, in this case the left, there was little immediate effect on the rhythm, but the P wave was changed to a negative. A–V rhythm was permanently established and conduction was apparently reversed, but with occasional reversed block. Incidentally this illustrates the dominant influence of the right vagus on the rhythmic mechanism in contrast with the effect of cutting the left vagus first, as shown in Plate V, Figures 39, 40, and 41. When the right vagus was cut first, the immediate effect was a release to S–A rhythm. However, block was established at first in the 2–1 ratio and later complete, as shown by the independent S–A and A–V rhythms persisting until the second nerve was cut, Figures 39 to 41. These two experiments illustrate observations made by Cohn (13) showing the preponderance of influence of the right vagus on rhythm and the left vagus on conduction, except in our case the fact is brought out by anoxemial stimulation of the vagal center.

When the second nerve was cut in experiments of this type there was always an immediate escape to a rapid rhythm and a perfectly sequential beat that persists through several minutes, 3 to 8, before abnormality of the electrocardiographic complex was again displayed. Figures 30, Plate IV, and 41, Plate V, illustrate such escape.

Figures 6, Plate I, 31 of Plate IV, and 42 of Plate V, illustrate the effects of direct cardiac final anoxemial asphyxiation. These figures present terminal stages of the series of complexes after the vagi are both cut. They are always in the late or terminal post-crisis stage of anoxemia. The first two figures show a final block of conduction with persistence of S–A rhythm. Anoxemia here reduces the conductivity of the bundle system at a time when rhythmicity is still persistent in the upper node. The A–V node is also reduced in rhythmicity, though that property is not always completely suppressed. In both experiments, after a time, occasional independent ventricular complexes occur. These are illustrated in Figures 32 and 33.

The tracing in Figure 42 illustrates the terminal anoxemia in which rhythm was first suppressed. Whether conduction was still possible could not be determined since all rhythm was suppressed.

This series of electrocardiograms on anoxemial dogs confirms our suspicion that the slowing of rate and suppression of sino-auricular rhythm in man in the early post-crisis stage is a vagus effect. This stage is entirely removed in the dog when the vagi are sectioned. Freed from vagus influence, the heart is capable of sustaining an effective rhythm for some seconds and a physiological rhythm detectable by the electrocardiograph for at least three to eight minutes. The series clarifies the entire group of questions as to the relative danger in procedures which induce human anoxemial asphyxiation.

SUMMARY OF ELECTROCARDIOGRAPHIC CHANGES IN THE DOG DURING THE POST-CRISIS STAGES OF ANOXEMIA.

1. Electrocardiograms reveal the fact that the early post-crisis cardiac slowing is a strictly vagal influence on rate.

2. The degree of vagal anoxemial stimulation may completely inhibit the S–A rhythm or only drive the rhythm to a lower focus in the tail of the node.

3. When S–A rhythm is inhibited A–V rhythm becomes dominant but at a lower rate plane, 40 to 50. When A–V rhythm is established internodal conduction may still persist but in the reversed direction, producing an inverted sequence.

4. Extreme anoxemial inhibition drives the rhythmic center down into the bundle branch, in the demonstrations described in this paper the left bundle branch. Rhythm may persist here with fairly regular sequence through a demonstrated series of 10 beats. Rhythm may be entirely suppressed.

5. When the first vagus nerve is cut during anoxemial vagal stimulation the type of electrocardiogram changes, according to which nerve is cut first. If the right is cut first then the S–A rhythm often reappears but interference with conduction persists so as to produce inhibitory block. If the left is cut first then A–V rhythm persists with reversed conduction or reversed block.

6. When the second vagus is cut the heart always leaps forward to a rapid rhythm with even greater acceleration

[2] Private communication. Quoted by permission.

than during the precrisis stage. The electrocardiograms show that this rhythm is perfectly normal and sequential in type.

7. After a prolonged series of vagus free beats, through several minutes in experiment 40, through 400 consecutive beats in experiment 41, direct cardiac anoxemia occurs. Direct anoxemia slows the S–A rhythm as shown in all experiments, suppresses internodal conduction first as in experiments 36 and 40, or suppresses rhythm first as in experiment 41. At this stage of anoxemia the A–V center does not take on the rhythm but may occasionally discharge beats. The S–A center, however, is apparently last to become quiescent under direct cardiac oxygen want.

GENERAL DISCUSSION OF THE RESULTS.

Early papers by Sherrington (14), Roaf and Sherrington (15), Lewis and Mathison (16), and Mathison (4) present the initial literature describing heart block as a result of asphyxia in the mammal. These authors used decerebrate, atorpinized, and uninjured cats. A careful reading of their papers clearly pictures heart block as an interruption of auriculo-ventricular conduction associated with a great slowing in the heart rate. Lewis and Mathison describe prolongation of the P–R interval as introductory to simple heart block beginning with a 2–1 rhythm and leading up to complete block. They describe complete dissociation, also "a marked retardation of the auricular rate and this likewise is independent of inhibitory influences," with speedy and complete recovery. Clearly they exclude the phenomenon of inhibition. Mathison attributes heart block to "lack of oxygen rather than accumulation of carbon dioxide." He says "cardiac inhibition frequently comes on before heart block can appear," but obviously he does not associate heart block and inhibition as causal phenomena. He reports heart block in dogs when the vagi are cut.

We are unable to confirm heart block at the stage described by the above authors as a change initiated locally in the conducting tissues. Without exception our experiments on dogs have never shown the pronounced early slowing with heart block if the vagi are first cut. The initial heart block is present if the vagi are intact, absent if the vagi are cut in dogs. We agree with Mathison that the phenomenon is strictly due to a lack of oxygen. But the lack of oxygen leads to a stimulation, then suppression of respirations and to a profound increase in activity of the vagal center either overlapping or quickly following the stage at which respirations cease. If the vagi are not injured and anoxemia is allowed to take its course without artificial respiration, there is always a composite picture ultimately showing depression of conduction to the point of block; slowing of the auricle, as we think, by inhibition of the S–A node; establishment of independent ventricular or A–V rhythm due to inhibition of the S–A rhythm; and the occurrence of bundle branch beats, all from inhibition.

If the vagi are cut, then the normal high rhythm persists with sequential beats that result in sustained blood pressure for a minute or so after respirations cease. The fast rate continues straight through the early period during which anoxemial inhibition occurs when the vagi are intact.

After a more or less prolonged period, three to five minutes following the respiratory pause, and when the blood pressure approaches zero and the heart beats can no longer be readily distinguished by the mercury manometer, then a second and direct disturbance of the heart rhythm occurs. There is great slowing of the rate, heart block and independent rhythms. There is loss of auricular rhythm due to reversed block or of ventricular rhythm from direct block. Finally complete cardiac pause ensues. This seems to be the stage observed by Mathison and the onset by his methods was more abrupt than we observed.

A difficulty in correlating these facts with those related in the literature depends upon the fact that Mathison and the others used rapid methods to induce asphyxiation. The method of occlusion of the trachea suddenly withholds oxygen and fails to remove carbon dioxide, as does also the rebreathing of pure nitrogen from a bag. Our method of rebreathing purified air progressively withdraws oxygen. The rate of withdrawal used by us allows the body tissues and organs to progressively adapt to the condition of oxygen lack. There is less danger from misleading secondary reactions. On the whole a truer picture of uncomplicated anoxemia seems to result.

Mathison and others do not record normal respirations when they do occur and it is difficult to determine from blood pressures alone the corresponding times in the asphyxial cycle. Mathison's experiment 5 shows a long period of large variations in the blood pressure and a slower heart rate induced at about 60 seconds after beginning nitrogen respirations. The high blood pressure and large pulse amplitudes suggest that this phenomenon can not be the late and final direct anoxemia described by us. We are at a loss to explain the difference unless the cat and dog show a fundamental variation in this regard. We refer in comparison to our Figures 1, 18, 22, and 24.

Haggard (11) has recently studied carbon monoxide asphyxiation in which the blood changes and the electrocardiographic responses were observed in animals poisoned by carbon monoxide gas. He carried experiments to fatal terminations, also recovered animals after gassing. He atropinized animals but did not operate as a method of removing vagus influence.

Haggard did not take continuous electrocardiograms but his intermittent tracings show cardiac phenomena which at one time or another we have obtained, with the exception of ventricular fibrillation. His Figures 3 to 9 and 11 to 13 contain complexes that are common enough pictures in progressive anoxemia as obtained by our methods. One could interpret his results as due to true anoxemia rather than due to carbon monoxide an interpretation on which Gasser and Loevenhart based their method for inducing anoxemia. In our experiments also "the cardio-inhibitory center maintains its activity longer than does the respiratory center." Haggard (p. 398) describes a phenomenon which he attributes to "fatigued cardio-inhibitory center." We obtained some not very conclusive evidence on this point. In the preceding pages we have given the facts and explanations which will clarify Haggard's observation that after atropine and carbon monoxide "the heart maintains a rapid rate until the time of respiratory failure. Following this, the rate slowed, the P-R time increased and A-V block developed, but without the stage of auricular cessation noted in the unatropinized animals." The statement could be made of dogs under anoxemia provided we considered only the very early and the final effects of anoxemia, pictures due to two very different causes. It is apparent that Haggard missed the beautiful sequence, probably true for monoxide

asphyxia as well as for simple anoxemia, by not taking continuous electrocardiograms.

We deem it more than probable that the cycle of circulatory events is fundamentally similar by the various methods of producing anoxemia. The sequence and intensity of the reactions, however, must vary with the rapidity of the onset and with the rate and thoroughness with which oxygen is removed from the tissues. In the last and final extreme reduction of cellular oxygen suppresses the fires of physiological processes. However resistant the tissue or organ may be, its activity is smothered by oxygen want.

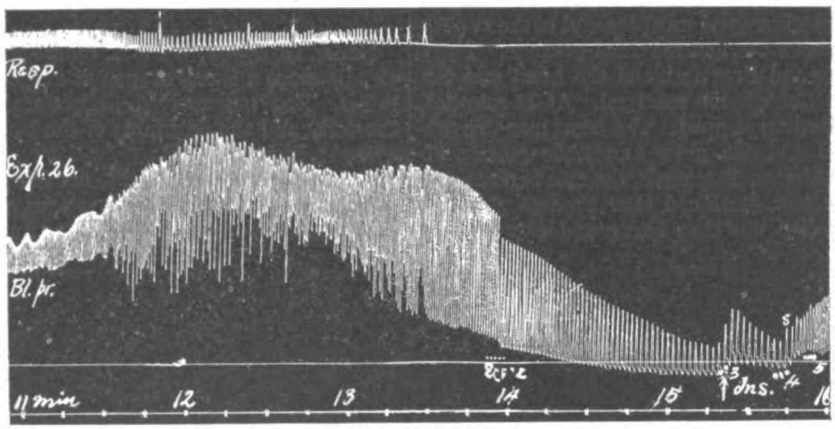


FIG. 1, EXPERIMENT 26.—The blood pressure and respiratory records show a somewhat unusual form of response to anoxemia. The blood pressure crisis exhibits two periods of maximal pressure with profound slowing of respiration at the onset of the first and stopping at the second. At 13 minutes 58 seconds the heart beat suddenly drops to a slower rate. Plate I, Figure 2, shows that this change is due to a shift from an S–A to an A–V rhythm. At 15 minutes 20 seconds insufflation was started. It had no influence on the electrocardiograms for 25 seconds when at 15 minutes 45 seconds regular sequential beats were reestablished on the particular beat marked S. (See also fig. 4.) The 10 beats following insufflation arise from a rhythmic point in the left bundle branch. Electrocardiograms are presented of the individual beats marked by dots. Magnification × 0.56.

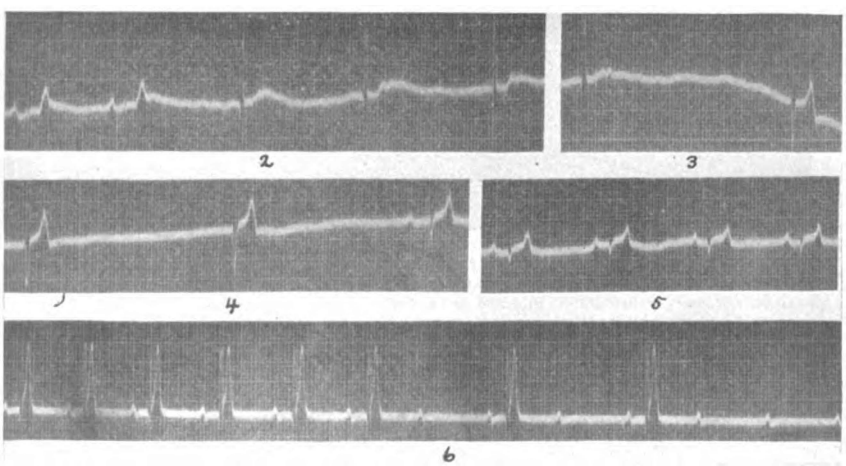


PLATE I. EXPERIMENT 26.—The positions of the electrocardiograms shown in Figures 2 to 5 of this plate are marked in the blood-pressure curve by dots under the corresponding beats. Figure 6 is the terminal record of experiment 36.

FIG. 2.—Five complexes recorded at 13 minutes 58 seconds, showing the shift in the rhythm from S–A to A–V origin. Extrinsic currents interfere but there is no very clear evidence of a P wave. Possibly the slight negative depressions in the T-waves of the last two complexes can be attributed to the auricle. There are 49 complexes in this group. Definite and clear reversed conduction characterizes the last 29.

FIG. 3.—At this point A–V rhythm with reversed conduction suddenly ceased and a ventricular complex characteristic of left ventricular dominance and bundle-branch origin began. This type runs for 10 successive contractions. These contractions are explained on the assumption of origin of the beat in the base of the left bundle branch.

FIG. 4.—The two complexes of left bundle-branch origin are followed by one sequential beat. Sequential contractions continued until complete recovery of normal rate and conduction. The sequential beats have at first a relatively long P–R interval, but conduction slowly improved under insufflation.

FIG. 5.—Fifth to eighth sequential beats during the recovery under insufflation.

FIG. 6.—This excerpt from a continuous electrocardiographic record of experiment 36 through seven minutes after respirations stopped shows the direct asphyxial effect on the heart when the vagi are cut. The rate progressively slowed to the auricular rate shown in this figure, 14 minutes. Then there occurred 2–1 block for two periods followed by complete block. During the last minute and a half of the entire record six independent ventricular complexes occurred. When the electrocardiographic record ceased the auricular rate was still 25 per minute and regular.

PROTOCOL.

Experiment 26, dog 12, wt. 10 K. Chloretone 0.3 gram per K., air allowance 3 liters, oxygen at the crises 4.5 per cent. Electrocardiograms.

This experiment ran through a very even and uniform precrisis period showing a gradual use of oxygen and little or no variations of blood pressure until the eleventh minute. Blood pressure then increased until the end of the twelfth minute, which marks the first maximal pressure. There was great slowing and irregularity of the heart rate but normal sequence through the maximal. At 13 minutes, 30 seconds, respirations stopped. The heart rate was progressively slowed and the pulse amplitude greatly increased. At 13 minutes, 58 seconds, the rate became suddenly very slow and continued slow through about 80 seconds. Insufflation was then begun and after 10 very slow beats recovery occurred rapidly, at 15 minutes, 45 seconds. This point is marked in Figure 1 by the letter S over the first normal or sequential contraction in the recovery.

Continuous electrocardiograms beginning at 12 minutes were obtained. (See Plate I, figs. 2 to 5.) The electrocardiograms showed slow and irregular rhythm but no abnormal sequences until 13 minutes, 58 seconds, when the rhythm shifted from an S–A to an A–V origin, Figure 2. With the shift the Q wave appeared and was followed by an exceptionally tall R wave, 16 mm., in comparison with the normal sequential complex which in this animal showed an R of only 2 to 3 mm. At 15 minutes, 22 seconds, the origin of the rhythm shifted to a still lower point in the A–V bundle system, Figure 3. The complex from the new focus has an S wave of 10 mm. amplitude and a tall positive T wave. It is typical of left ventricular dominance but its type shows bundle origin. The focal center is apparently in the left bundle branch and remains he re for the next 10 beats. After 10 beats insufflation introduced enough oxygen to bring about a normal sequential heart beat of increasing rate and final recovery.

This whole phenomenon is interpreted as vagal stimulation by anoxemia at the center. The most striking new observation is the fact that anoxemia affects the vagal center profoundly enough to drive the rhythm to a point so low as the left bundle branch.

PROTOCOL.

Exper. 29, dog 13, Wt. 9 K. Chloretone 0.3 gram per K., air allowance 4 liters, oxygen at end 2.2 per cent. Vagi intact. Dog not revived. Electrocardiograms through the early and the beginning of the late anoxemial state, Plate II, Figures 8 to 16.

Anesthesia relatively light, occasional skeletal muscle contractions during the early stages of the experiment. Respirations rapid at the beginning but very slow and ir-

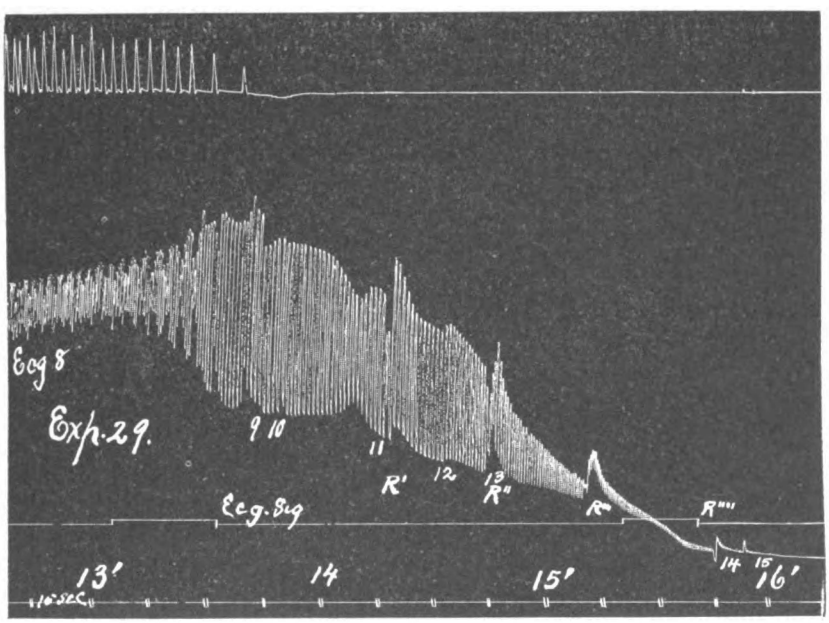


FIG. 7.—EXPERIMENT 29.—The respiratory and blood-pressure tracings at the terminus of the test. Top line respiratory movements which ceased at 13 minutes 44 seconds. Middle line blood pressure. The maximum or crisis occurred at 13 minutes 30 seconds. The numbers below the blood-pressure tracing indicate points figured in the electrocardiograms, Plate II, Figures 10 to 17, inclusive. *R'*, *R''*, *R'''*. *R''''* respiratory gasps occurred after rhythmic respirations had ceased. No attempt at recovery. Magnification × 0.68.

regular from the fourth to the eighth minute and regular and typical during the last portion of the test.

Blood pressure was more sensitive to external or reflex stimulation than usual. There were two maximal pressure waves separated by 1.5 minutes, Figure 7. From 13 minutes, the heart progressively slowed until at the last respiration the pulse amplitude was 70 mm. From the moment of the last respiration blood pressure fell uniformly through 2.5 minutes, when the heartbeats were no longer strong enough to record. The heart rate remained uniformly slow through seventy-odd seconds, then gradually increased in rate but still decreased in amplitude. At 16 minutes, the pulse cannot be counted on the blood-pressure tracing, though it is clear and sequential in the electrocardiograms.

There were four respiratory gasps after regular respirations stopped. The second and third are followed by a slight increase in heart rate.

The electrocardiograms showed the usual normal—P 2 mm., Q slight, R 21 mm., S none, T negative 4.5 mm., P–R 0.098 seconds, R–T 0.200 seconds, rate 140 per minute.

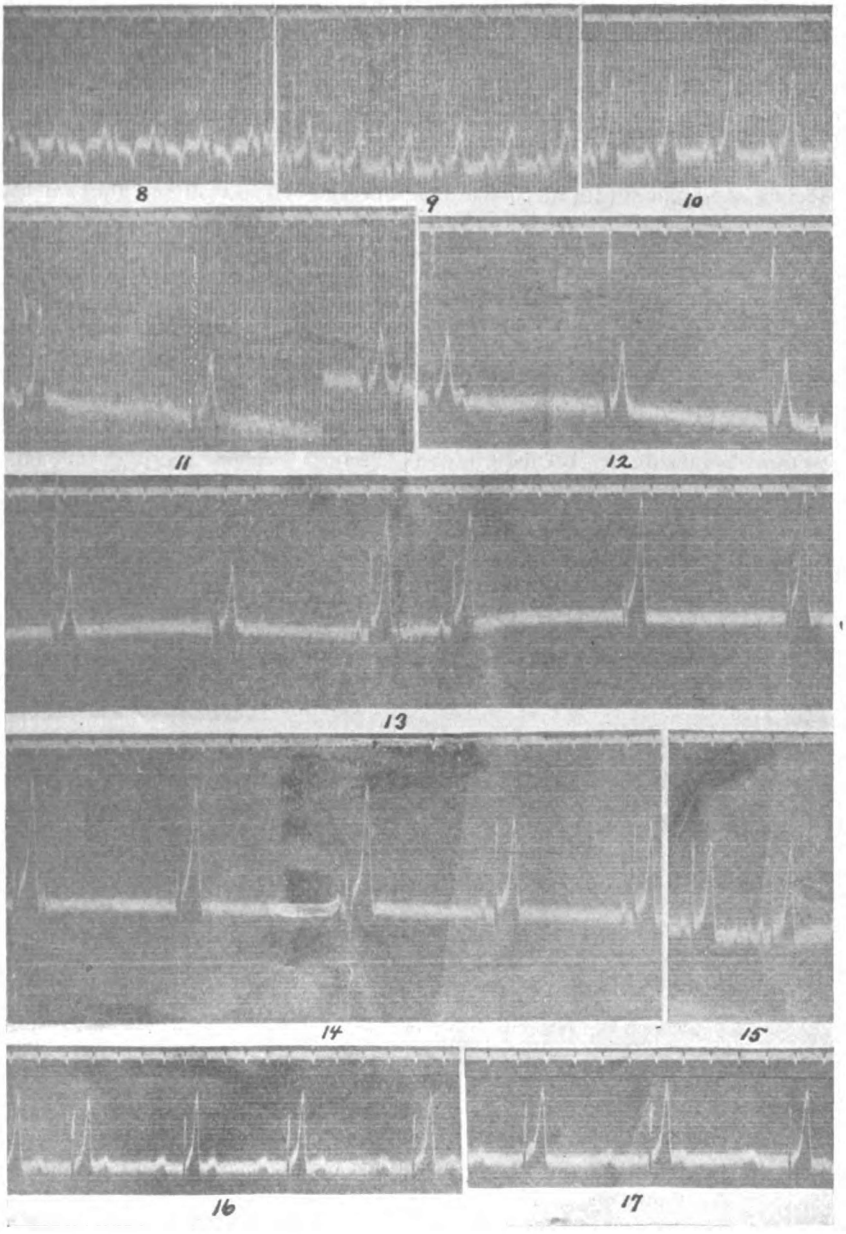


PLATE II, EXPERIMENT 29.—FIG. 8.—Normal electrocardiograms. Note the characteristic tall R and the negative T waves.

FIG. 9.—Time, 12 minutes 23 seconds. The T wave had changed from a negative to a positive 16 seconds earlier. R now decreasing.

FIG. 10.—Time, 12 minutes 53 seconds. Both the R and the T waves progressively increased between Figures 9 and 10.

FIG. 11.—Time, 13 minutes 42 seconds. Rapid inhibitory slowing of the rate (vagal) during the preceding 10 beats. S-A rhythm inhibited and A-V established at this point. Reversed conduction continued through 9 beats with block on the second, third, and ninth between this and Figure 12.

FIG. 12.—Time, 13 minutes 56 seconds. Reversed conduction blocked in the second complex and permanently blocked in a series of complexes following this point. Note the delay of reversed conduction in the third complex compared with the first in this figure.

FIG. 13.—Time, 14 minutes 15 seconds. Transitions occur in the pacemaker along the A-V node ending in a ventricular beat with left dominance in the last complex. The third and fourth complexes occur at the first anoxemial respiratory gasp, shown in the blood-pressure curve, Figure 7, and are due to momentary but partial suppression of the vagal inhibition.

FIG. 14.—Time, 14 minutes 30 seconds. Sudden transition from deep A-V rhythm to a normal sequential but slow rhythm. From this point no further irregularities in sequence occur until permanent block appeared 80 seconds later.

FIG. 15.—Time 14 minutes 45 seconds. Momentary auricular flutter at the second respiratory gasp shown in Figure 13. Sequence normal when it occurs.

FIG. 16.—Time, 15 minutes 50 seconds. Appearance of direct anoxemial block to 2-1 rhythm. For the preceding 30 seconds the P-R became progressively longer, from 0.12 second to 0.28 second. The duration of the auricular contraction also progressively increased as shown in this figure.

FIG. 17.—Time, 16 minutes. Establishment of permanent block but with both S-A and A-V rhythms still occurring. The record not taken beyond this point.

At 12 minutes, 7 seconds, the T wave became positive. At 12 minutes, 23 seconds, Figure 2, the T wave had increased to 6.5 mm. At 12 minutes, 53 seconds, the T had reached an amplitude of 12 to 14 mm. At about 13 minutes, 30 seconds, the slowing is more pronounced, and at 13 minutes, 42 seconds, S–A ryhthm was inhibited and A–V rhythm established, Figure 11, Plate II. The type of reversed conduction shown in the third complex of Figure 11 continues through 9 beats, after which for 23 consecutive beats there was no evidence of auricular action. The twenty-fourth and twenty-fifth beats, the third and fourth of Figure 13, are sequential. At this point the first respiratory gasp shown in Figure 7 occurred. These are followed by 10 beats with no P wave in evidence.

On the last complex of Figure 13, the character of the complex changes. There is now a very short R wave, deep and profound S, and a continued tall T. This is a typical left ventricular dominance. This we also explain by assuming that at this point the origin of the rhythm shifted down the A–V node to a still lower point in the conducting system, to the left bundle branch. This type of beat gradually shifted back to the normal sequential beat as shown in Figure 14. The first complex in Figure 14 introduced reversed conduction. In the third complex the P wave occurred before the ventricular complex, and in the fourth and fifth the regular sequential beats appeared and continued for some 12 beats before a second respiratory disturbance occurred. The third complex in Figure 14 shows left ventricular dominance but an auricular beat occurs higher up either in the tail of the S–A node or in the atrial groove. Possibly the left ventricular type in this case can be attributed to relative right bundle block rather than left bundle rhythm. If so, it would indicate an influence of the vagus nerve on conduction extending well down into the ventricular portion of the bundle system and greater on the right bundle.

Sequential beats continued from 14 minutes 30 seconds through to 15 minutes 50 seconds, when partial 2–1 block occurred as shown in Figure 16. In the meantime the duration of the P wave and the length of the P–R interval very progressively increased to the extreme degree shown in Figure 16, when 2–1 block was established. The electrocardiographic record ceased at 16 minutes with the type of record shown in Figure 17, 2 minutes 20 seconds after respirations ceased.

The reestablishment of sequential beats after the extreme inhibition shown in the first anoxemial slowing indicates a partial escape from the vagal inhibition of conduction. Henderson and Haggard have given evidence indicating a similar phenomenon of escape after carbon monoxide asphyxiation.

PROTOCOL.

Exper. 33, dog 16, wt. 7.5 K. Chloretone 0.3 gram per K., air allowance 4 liters, oxygen reached 4.37 per cent. Vagi intact. Electrocardiograms throughout the critical asphyxial stage, Plate III, Figures 19 to 21.

An excellent record of respirations and blood pressure was obtained with unusual features in the terminal phase. Electrocardiograms continue through the entire critical post-crisis period, Figure 18, and Plate III, Figures 19, 20, and 21. The respiratory record shows a very uniform consumption of oxygen to 10 minutes, a progressive falling off of oxygen used until respiration ceased at 12 minutes 20 seconds.

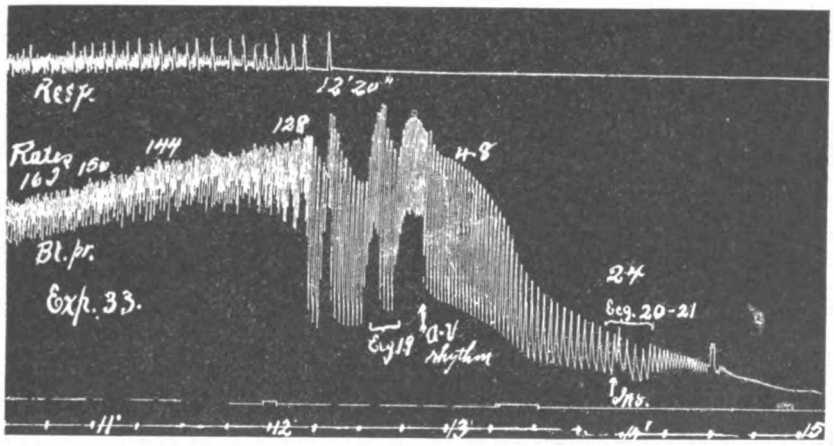


FIG. 18, EXPERIMENT 33.—The terminal stage of experiment 33, vagi intact. The numbers above the blood-pressure curve are heart rates per minute. At the blood-pressure crisis three great irregularities in the heart rate appear, i.e., three groups of slow rates each followed by a momentary recovery. These periods are in reality 2–1 blocks as shown by the electrocardiograms, Plate III, Figure 19. *Ecg. 1* and *ecg. 2–3* are figured in Plate III. *A–V rhythm* marks the point where the S–A rhythm was completely inhibited. *Ins.*, insufflation began. On the fifth beat, the last complex of Figure 21 of the electrocardiographic series, normal S–A rhythm was reestablished. Magnification × 0.59.

The rise of blood pressure was sharp during the crisis, notwithstanding the fact that the heart rate slowly decreased from 160 at 10 minutes 40 seconds to 128 at the time of maximum pressure, 12 minutes. There are four periods of pronounced cardiac slowing during the thirteenth minute, the first occurring between the last two respirations, Figure 18.

At the beginning of the 4th pronounced period of slowing marked *A–V rhythm* on the figure, auricular contractions disappeared, leaving a pure ventricular complex. Occasionally there was reversed conduction with a rather long R–P interval, Figures 20 and 21. Beginning with the last complex in Figure 21, sequential rhythm was established, and the rate increased as shown in the blood-pressure tracing, Figure 18. This was possibly a release from the vagus anoxemial inhibition on account of the entrance of air obtained through insufflation begun at 13 minutes 55 seconds. However, no recovery of the animal occurred.

PROTOCOL.

Exper. 36, dog 18, wt. 10 K., chloretone and ether, air allowance 4.5 liters, oxygen at the end 3.46 per cent. Vagi cut at the beginning. Dog not revived. Continuous electrocardiograms for 6 minutes, beginning 10 seconds before respirations ceased, Plate I, Figure 6.

Respirations very irregular, rather rapid until the last minute when they slowed down at the anoxemial crisis.

The blood pressure increased at the moment both vagi were cut at the beginning of the experiment and remained high until anoxemia appeared. The pressure then very gradually decreased with failing respiration. No slow beats at the crisis, very regular heart rate with gradual decrease in pulse amplitude until the variations were no longer recorded by the manometer, Figure 22. Sequential complexes figured are 0.200 second, 0.200, 0.200, 0.208, 0.212, 0.220, 0.232, block, 0.228, block now complete. Six irregular and independent ventricular complexes occurred late after the development of block.

PROTOCOL.

Exper. 38, dog 19, wt. 9 K., chloretone 0.3 gram per K., air allowance 4 liters, oxygen at crisis 2.38 per cent. No electrocardiograms. Respiratory and blood-pressure curves.

Respirations rapid, use of oxygen uniform, but decreasing at the very last before respirations ceased at 14 minutes 16 seconds.

The rise of blood pressure was moderate at the crisis. Heart rate at its maximum at 13 minutes 30 seconds, near the crest of maximal blood pressure. The heart

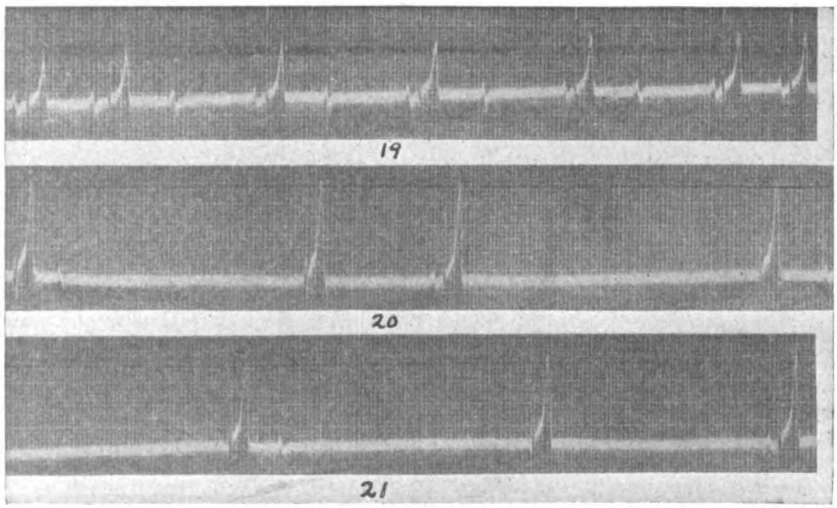


PLATE III, EXPERIMENT 33.—FIG. 19.—This figures the third group of four beats at a slow rate as shown in the blood-pressure curve of experiment 33. Four auricular contractions are shown to be blocked and a 2-1 rhythm occurs. Recovery of conduction extended through the succeeding rapid period shown in the blood-pressure curve.

FIG. 20.—An A-V rhythm has persisted through the preceding 70 seconds. Reversed conduction occurs occasionally only. It is shown in the first and fourth complexes of this figure. Reversed block occurs in the second complex. The third complex is produced by an escape to S-A rhythm at the moment when insufflation began, see the blood-pressure curve, Figure 18.

FIG. 21.—Continuation of Figure 20, showing reversed conduction, block, and the permanent return of S-A control beginning with the fast complex. From this point on sequence is normal and the rate progressively increases.

heart beats to 14 minutes 30 seconds, Plate I, Figure 6. At 4 minutes 5 seconds after respirations stopped, complete block occurred. The auricle continued to beat with regular but decreasing rhythm for 7 minutes 35 seconds after respirations ceased. The auricular rate was 25 per minute at this time when the electrocardio-graphic record was stopped. The development of heart block in this experiment was like that in experiment 40, Plate IV, Figure 32.

In this experiment conduction was first eliminated in the late anoxemial asphyxiation of the tissue as in experiment 40. The electrocardiograms show that the inception of block was preceded by a group of rapidly lengthening P–R intervals. The P–R intervals in the slowing began about 30 seconds before the respirations ceased, became very profound at 14 minutes 35 seconds, with a rate of 44 per minute. The right vagus was cut at 14 minutes 58 seconds. The rate immediately doubled in partial release. The left vagus was cut at 15 minutes 40 seconds. At this point the rate was released to 216 per minute, a greater rate than at the maximal blood pressure. During the interval between the cutting of the right and left vagus nerves the blood pressure was relatively high and the pulse amplitude great. (See Fig. 23.)

Artificial respirations were established before anoxemia had advanced to the second asphyxial stage, natural respirations returned at 17 minutes 15 seconds.

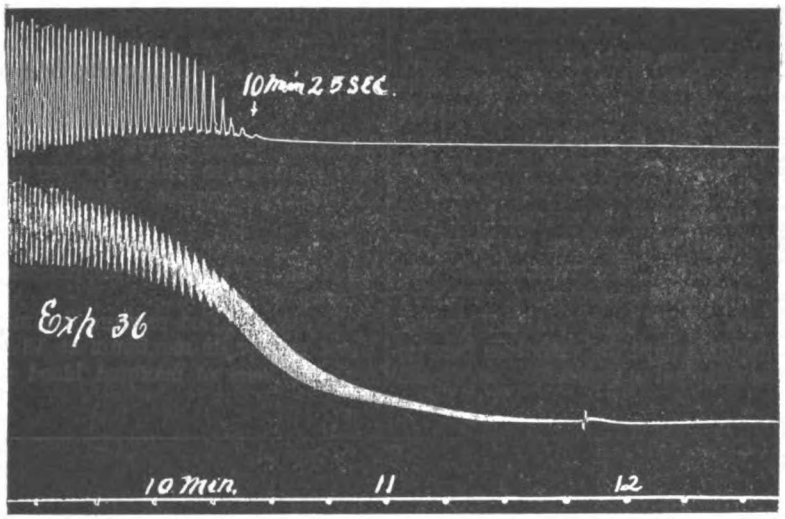


FIG. 22, EXPERIMENT 36.—Showing the terminal respiratory and blood-pressure records of a comparatively infrequent type of response to anoxemia when the vagi are cut at the beginning of the test. Respirations ceased at 10 minutes 25 seconds while the dog was inspiring 3.62 per cent oxygen and 0.45 per cent carbon dioxide. The blood pressure declined earlier than the rule, but the heart rate was sustained in normal sequence for 3.5 minutes and the auricles still contracted at the end of 17.5 minutes when the record was discontinued. Figure 6, Plate I, shows the beginning of direct asphyxial heart block at 14 minutes. Magnification × 0.76.

PROTOCOL.

Exper. 40, dog 20, wt. 16 K., chloretone 0.3 gram per K., air allowance 4 liters, oxygen at end 2.5 per cent. Electrocardiograms. Vagi cut during the cardiac slowing following the respiratory crisis. Insufflation but no recovery.

The blood pressure was very uniform and even until the sixth minute when the pressure began to rise and the heart rate to increase. The maximum pressure was reached at the moment when respirations stopped, although the average high pressure was maintained one minute and more longer.

Between the last two respirations 22 heart beats occurred. Following the last respiration there are 56 beats to the point marked *left vaguscut*, Figure 24. These groups are each slower than the preceding. At the last group of 12 beats the blood pressure was 158 and the pulse amplitude 80. When the left vagus was cut slow swinging pulses occurred to the point marked *R. V. cut*. There are four slight irregularities in this series; otherwise they are remarkably even, though the pulse amplitudes progressively decreased. Counting the four irregularities, there are 62 beats in the interval. When the right vagus

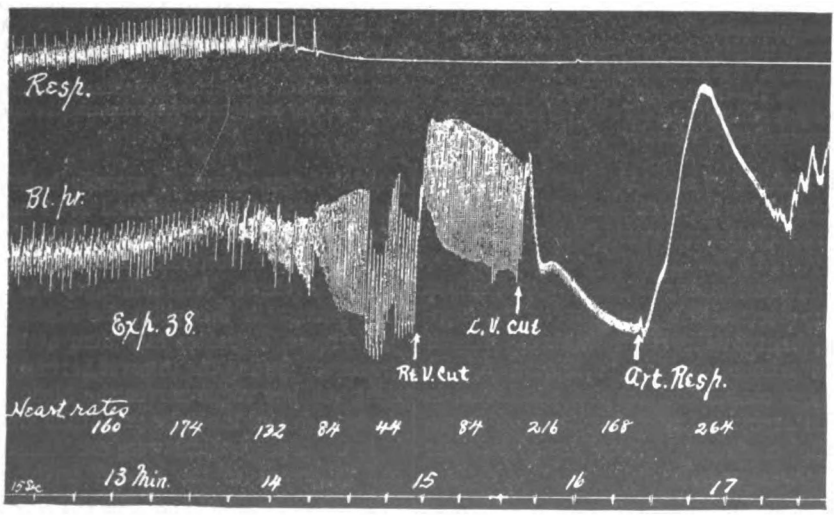


FIG. 23, EXPERIMENT 38.—Slowing of the heart rate began at 13 minutes 40 seconds, and at 14 minutes 30 seconds had dropped to 44. The right vagus was cut at the point marked. There was an immediate increase of the rate to 88 per minute. When the left vagus was cut the rate immediately escaped to the precrisis figure and rapidly ran up to 216 per minute. No electrocardiograms were obtained. The heart rates are given on the tracing. Magnification × 0.54.

was cut the pressure was 122 with pulse amplitudes of 68. Instantly the heart rate increased and the pressure struck a maximum of 130, rapidly falling to 108 in 8 or 10 seconds. After a small group of very irregular pressures a very regular series of heart beats and even pressure variations occurred through 25 seconds, the pressure at the beginning averaging 86. At the end of this regular group the pressure was 76. Insufflation then produced irregularities in the blood pressure, which, however, continued to fall. No recovery was obtained.

The normal electrocardiogram did not vary from the usual type. The R was tall, 23 mm., and T diphasic with the negative wave moderate. This type continued through the records of the fourth and eighth minutes. Continuous electrocardiograms began at 8 minutes 55 seconds, and ran through the entire post crisis. At the beginning of the continuous record the T wave was positive, 9 mm. in amplitude. By counting the regular beats corresponding to the first, second, and third blood-pressure groups preceding the cutting of the left vagus, it was easy to identify the

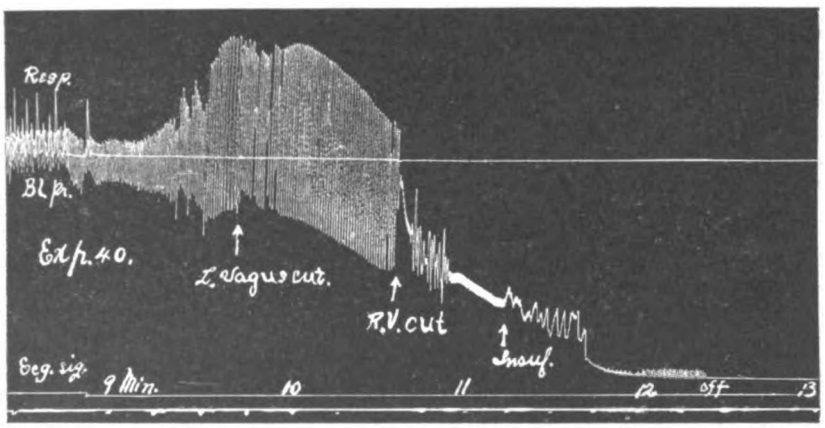


FIG. 24, EXPERIMENT 40.—Respirations stop at 8 minutes 56 seconds. Fifty seconds later the left vagus was cut. At 10 minutes 35 seconds the right vagus was cut. *Insuf.*, insufflation began but changed to bellows and stopped at *off*. No recovery. The electrocardiographic record was continuous from 8 minutes 54 seconds to 17 minutes 40 seconds. At 12 minutes 50 seconds independent auricular and ventricular rhythms, i.e., complete block, was established. At 14 minutes 40 seconds the auricular electrocardiograms were still regular but became too weak to photograph. At 17 minutes 40 seconds the ventricle was contracting irregularly at about 6 per minute. The record was then stopped at 7 minutes 46 seconds after natural respirations ceased. The time line is raised to 30 mm. pressure. Magnification × 0.59.

irregularities in the electrocardiograms. They are associated with a series of progressive shortenings of the P–R intervals. Measuring straight through the three irregular periods shown in the blood-pressure record before the left vagus was cut we have the following P–R times in order: First beat, 0.112 second; second, 0.100; third, 0.092; fourth, 0.080; fifth, 0.084; sixth, 0.064; seventh, 0.072; eighth, 0.052; ninth, 0.012; tenth, 000; eleventh, 0.128; twelfth, 0.100; thirteenth, 0.112; fourteenth, 0.108; fifteenth, 0.092; sixteenth, 0.052; seventeenth, 000; eighteenth, 0.136; nineteenth, 0.116; twentieth, 0.100; twenty-first, 0.088; twenty-second, 0.056; twenty-third, 0.020; twenty-fourth, —0.040 (reversed conduction); twenty-fifth, 0.112; twenty-sixth, 0.092; twenty-seventh, 0.088; twenty-eighth, 0.084; twenty-ninth, 0.120. These conduction times identify the irregularities as due to a progressive displacement of the rhythmic center in the descending direction the most striking in our series. The tenth, seventeenth, and twenty-fourth are the critical complexes, Plate IV, Figure 28.

At the point marked, "Plate IV, Figure 29," the first or left vagus was cut. The two beats preceding the section of the nerve have buried P waves, so also the first beat following the cut. The third complex shows a well-marked reversed conduction, the P wave occurring late in the T. This auricular complex began a series of negative P waves running through the entire group of electrocardiograms until the second or right vagus was cut. The fifth beat showed a reversed conduction time of 0.216 second, in the sixth beat the R–P interval is 0.328 second, if indeed this P should not be considered as belonging to the following complex. The next five or six contractions introduce variations of similar type, and this phenomenon recurred at intervals until the second vagus was cut. Certain ventricular complexes show no associated auricular contractions.

At the intervals between the fifty-eighth and sixty-third beats after cutting the left vagus, there are variations in the iso-electric period which mark the lifting and cutting of the right vagus nerve. Although the nerve was cut promptly the exact point of cutting is in doubt. The sixty-fourth beat is partially recorded only. The sixty-fifth beat and the series that follow are normal sequential complexes increasing very rapidly in rate and decreasing in the amplitude of the T, through eighteen or twenty beats. The eighteenth recovery beat is at a rate of 242, P–R 0.104 second, R–T 0.104 second, P 1.6 with rather broad base, Q 1, R 17, S none, and T 7. After the twenty-second beat there was some irregularity in the sequence.

For about 40 seconds following the section of the second vagus the record was regular and uniform with slight broad wavelike variations (suggestive of some extrinsic influence). At the stage of anoxemia when these end the T waves greatly augment, changing from 6 to 10 mm. in about ten beats. The P–R interval lengthens to 0.14 second. At the end of the tracing the T wave had increased to 16 mm. and the P–R to 0.16 second and the rate had slowed to 106 per minute. These complexes are regular and slow sequential beats with tall T waves and increasingly long P–R intervals. The ten complexes preceding complete and final block have P–R intervals that measure 0.136 second, 0.152, 0.152, 0.160, 0.160, 0.168, 0.220, 0.232, block, and 0.248. All succeeding contractions are blocked, Figure

31. A regular auricular rhythm continued through about 2 minutes but the P waves became increasingly faint until they could not be distinguished at 14 minutes 50 seconds.

Occasional ventricular complexes occur during this time. The first one is fused with an auricular complex, the second, third, and fourth are obviously independent, and fifth appears so but follows a P wave by 0.092 second, the sixth and seventh follow P waves by 0.180 second, the eighth by 0.008 second, and in the ninth P is buried in the ventricular complex. The ventricular rhythm is obviously wholly independent.

The auricular rate dropped from 100 to about 26 per minute during the time of block. Ventricular complexes only are visible throughout the electrocardiographic records of the fifth and sixth minutes after respirations ceased. These are at a low but fairly regular rate, about 12 per minute at first but 6 per minute in the tracing which closes our record, Figure 33.

The disturbances following the stopping of respiration can in this case all be attributed to vagospasm. They disappear on cutting both vagus nerves. The sequential rhythm that returns is perfectly comparable to that of experiments in which the vagus nerves were cut before anoxemial asphyxiation began. In this experiment when the heart itself became asphyxiated sequential beats were suddenly stopped by block. The auricle continued in regular rhythm through many seconds until finally the auricular complex became too faint to be distinguished. In the meantime independent ventricular complexes at long but comparatively regular intervals appeared and persisted to the end of our record. The appearance of augmented T waves with the onset of the period of slowing

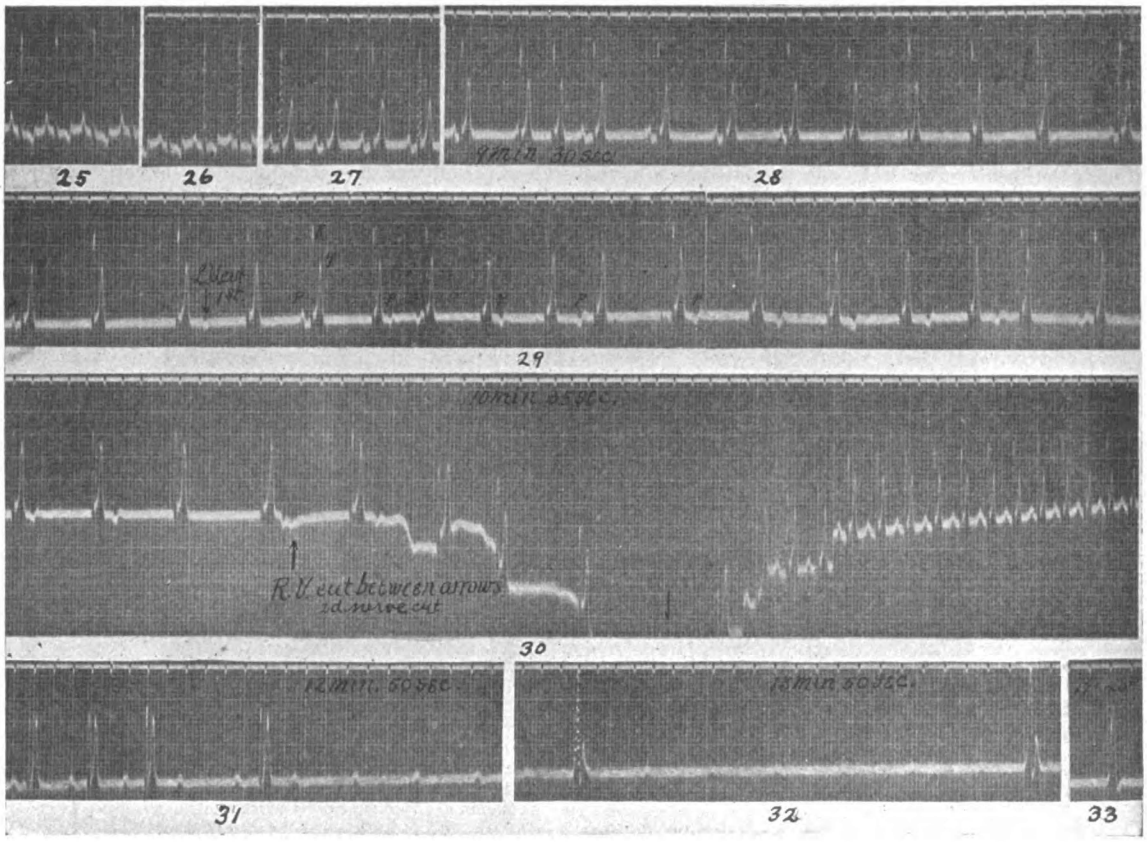


PLATE IV, EXPERIMENT 40.—FIG. 25.—Normal electrocardiograms, showing negative T waves.

FIG. 26.—Seven minutes 30 seconds from the beginning of the anoxemial test.

FIG. 27.—Eight minutes 55 seconds from the beginning of anoxemia. End of respirations. T wave became positive at 8 minutes.

FIG. 28.—Nine minutes 30 seconds. Periodic inhibitory displacement of the rhythmic center in the descending direction, each period ending in apparent block but probably buried P waves.

FIG. 29.—The left vagus was cut at the mark *L. V. cut*, 9 minutes 50 seconds. In the third complex the P is inverted and conduction is retrogressive. From this point through the interval before the cutting of the second vagus the P wave was always inverted. conduction was reversed and occasionally there was reversed block.

FIG. 30.—At 10 minutes 35 seconds the second or right vagus was cut somewhere between the points marked, probably at the second arrow. After a few beats normal sequential rhythm was rapidly reestablished, the rate increasing through the first 10 or 15 contractions following the second arrow.

FIG. 31.—At 12 minutes 50 seconds, or 2 minutes 15 seconds after both vagi were sectioned, complete anoxemial block appeared. The auricle continued to beat in regular rhythm from the S-A center but the ventricle ceased beating. After a long interval occasional independent ventricular complexes appeared with increasing frequency.

FIG. 32.—Thirteen minutes 50 seconds. The ventricle now contracted at the rate of 14 to 15 per minute. The auricular rate was about 90. One minute later the auricular complexes were too weak to record.

FIG. 33.—The last recorded ventricular complex, 17 minutes 40 seconds after respirations ceased.

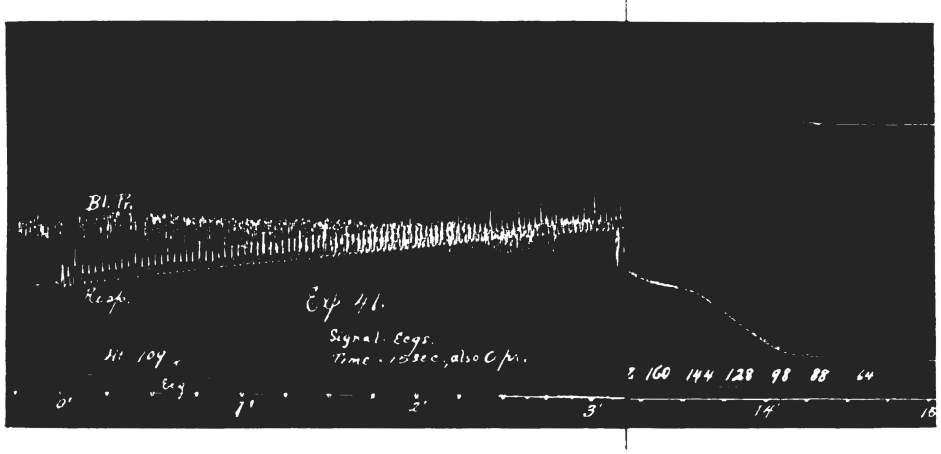
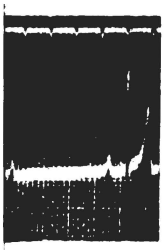
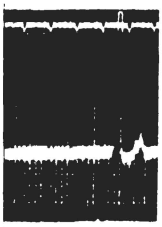
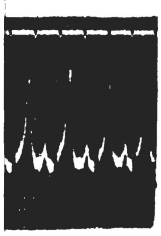


FIG. 34, EXPERIMENT 41.—Blood pressure and respirations through the entrations of any kind. Note the uniform rate of oxygen consumption until the anoxemial crisis approached. The origin







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of the heart from cardiac tissue anoxemia was typical of the course of other experiments.

Insufflation used late in the test when blood pressure was low but while normal electrocardiograms were running was unsuccessful toward reviving the animal, in fact had no observable effects.

PROTOCOL.

Exper. 41, dog 19, wt. 19 K., chloretone 0.3 gram per K., air allowance 4 liters, oxygen reduced to 1.8 per cent, electrocardiograms, blood pressure, vagi cut at the crisis.

Respirations comparatively regular for 6 minutes, then rapid and irregular to 7 minutes, increasing rate and amplitude to 9 minutes, decreasing amplitude 9 to 11 minutes, decreasing rate 10 to 11 minutes. Respirations cease at 11 minutes. For the first 6 minutes deeper individual inspirations occur about every sixth respiration, from 6 to 8 minutes fewer deep inspirations, from 8 to 10 minutes more frequent deep gasps that become very marked near the end at 11 minutes.

The blood pressure was very uniform and even, one of the most regular records of the series. After 5 minutes it slowly and progressively increased to a maximum at 10 minutes 25 seconds. The maximum pressure came about 40 seconds before respirations stopped but after a decrease in the use of oxygen was apparent. The blood pressure fell very slightly through 40 seconds, then somewhat more rapidly until the vagus nerves were cut. (See fig. 24.) Later the pressure fell promptly to the level shown in the figure. The events are figured through only 4 minutes after respirations stopped.

The heart rate began at 109 per minute. In the fifth minute it had increased to 118, 121 in the eighth, 156 in the tenth, and 161 at 10 minutes 15 seconds. The rate rapidly fell then to 145 and finally 44 when the right vagus was cut. There were no changes in heart rate between the cutting of the right and left vagi. When the second or left vagus was cut the rate immediately increased to a maximum of 185, then decreased through the rates shown in the figure to 64 at 14 minutes 40 seconds, after which the manometer no longer recorded, though the electrocardiograph recorded complexes for 30 seconds more, when the heart stopped completely as shown in Plate V, Figure 42.

When the second vagus was cut the blood pressure immediately increased, then dropped again in 5 seconds, Figure 34. This was followed by a slight second rise in pressure, then a progressive decline through 2 minutes 25 seconds, when the heart beats were no longer visible on the manometric record. The heart rates through this period were as follows: 15 seconds before the vagus was cut 11 beats, and by 15-second periods after cutting, 44, 40, 40, 40, 36, 30, 24, and 20 on the ninth period, but for the tenth not visible.

The continuous electrocardiographic tracing, beginning at 8 minutes 45 seconds, shows beside the cardiac complexes certain gross waves corresponding to the respiratory rhythm. Periodically these waves are larger and check with the recorded deep sighing inspirations shown in the respiratory record. They aid in marking the end of active respirations in the rapidly moving electrocardiographic film.

The normal electrocardiograms show the following type. The rate is relatively high, 109 per minute. The P wave is positive and sharply defined, the P–R intervals average 0.14 second. The ventricular complex begins with a sharp abrupt R wave of short duration and large amplitude. There is only a slight S wave. The T is diphasic, with a sharp negative deflection which ends in an abrupt positive, the two of about equal amplitude. The duration of the R–T interval is 0.24 second.

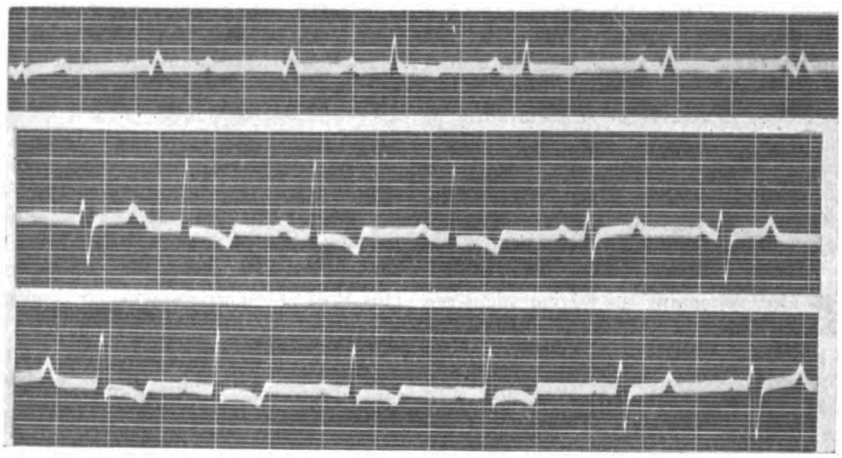

PLATE VI, FIGURE 43.—Electrocardiogram showing the displacement of the pacemaker to the left bundle branch in a dog under the influence of morphine. This experiment was obtained by Dr. Frank N. Wilson and Dr. George R. Hermann, by whose kind permission it is here reproduced. The three conventional leads are shown.

At 8 minutes 45 seconds the rate had increased to 150, with a shortening of the P–R interval to 0.112 second. At 9 minutes 30 seconds the rate was 156, P–R time 0.110 second. The R had increased in amplitude to 20 mm. against the normal of 17. The heart rate reached its maximum of 161 at 10 minutes, P–R 0.096 second, R–T 0.21 second.

At 10 minutes 30 seconds the heart rate was 159. P–R now 0.088 second, the shortest conduction interval shown in the tracing. The T wave was no longer diphasic but terminated in a sharp positive of 5 mm. From this point on until respirations stopped the T wave gradually and progressively increased in amplitude to a maximum of 11 mm. at 11 minutes 20 seconds, 4 or 5 seconds after the stopping of respiration. Beginning at 11 minutes, the rates computed from 10-second intervals are 145, 109, and

44. These changes in rate are accompanied by an increase in the conduction time as shown by the longer P–R intervals. The R wave decreased in amplitude through 19, 18, and 15 mm., respectively. During the 30 seconds of progressive slowing of rate the blood pressure fell. There was a corresponding increase in the pulse amplitude.

The first or right vagus nerve was cut at the point marked in Figure 39, Plate V, 11 minutes, 35 seconds. There were five slow swinging pulses just before the nerve was cut. Inhibition increased until the S–A rhythm gave place to an A–V rhythm, as shown in the last three complexes before the right vagus was cut. The last complex shows reversed sequence, the auricle contracting in response to A–V rhythm as in the human (2). (Fig. 9, Plate I.) When the first or right vagus was cut there was temporary release from inhibition to a faster rate and normal sequential beat. After two beats a 2–1 rhythm returned for five or six groups before complete block occurred.

The ventricular rhythm during the vagospasm was very regular, rate 44. The auricular rate was absolutely irregular. The P wave was positive throughout, but the P–P intervals have no regularity and cannot be lined with the ventricular complexes during this time. The intact left vagus does not inhibit the S–A nodal rhythm but it does block conduction.

On cutting the second or left vagus at 12 minutes 10 seconds the normal sequential type of electrocardiograms immediately returned, Figure 41, Plate V. The return rate was greatly augmented during the first few beats. This was without change in the P–R and R–T intervals but with a tremendous increase in the amplitude of the T wave.

Sequential beats after sectioning the second vagus ran a continuous series for 400 consecutive beats before rhythm suddenly ceased as shown in Plate V, Figure 42. During this series the rate progressively decreased. The electrocardiograms were remarkably regular and uniform in character. However, one striking phenomenon recurred here, namely, the augmentation of the T wave as direct cardiac anoxemia advanced. This phenomenon begins in this test early, by the reversal of the normal initial negative T. The amplitude rapidly increased at about the time respirations stopped. The T wave took on the tall type characteristic of A–V nodal rhythm during the vagospasm. When the second nerve was cut the T waves were at once almost as tall as the R waves and became taller to the end while the R waves progressively decreased.

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—By courtesy of the American Journal of Physiology.

A METHOD FOR MEASURING RETINAL SENSITIVITY.

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INTRODUCTORY.

In examining the candidate for flying status during the national emergency the search for a means of rating the visual capacity better and more complete than the usual letter test, recalled the fact, already known to workers in sense physiology, that attempts to measure visual sensitiveness to perception of small contrasts gave highly variable results, ambiguous unless time were taken to accumulate a large number of data, from which the effect of the variations could be eliminated by taking the average. The variations in such results are comparable, in their order of magnitude, to the very quantity which they measure, and the attempt to make such measurements, within the limits of time available and of equipment as yet adapted to the use of the opthalmologist gave results which were unsatisfactory and meaningless.

A test at one time experimentally practiced in the Air Service involved the use of a smoke wedge.[1] The subject was to draw the wedge slowly across a sight-hole until the test object ceased to be distinguishable. This latter was a 1-inch square of gray, mounted centrally upon a 2-inch square of lighter gray paper "where there are 13 perceptible differences between the two squares" (Nos. 32 and 19, respectively, in the series of papers in which white is No. 1, and black is No. 50). As a check, the same device was used, except that the smaller square was replaced by a 20/50 Snellen illiterate "E" of the same gray. This was the procedure for contrast sensitivity. For threshold sensitivity, the test object used was a 3-millimeter aperture in the iris diaphragm on the De Zeng stand, with specifications as to the lamp used and as to the general conditions of illumination of the room as they would affect the state of adaptation. In all cases the test was to be accomplished in not less than 5, nor more than 8 seconds, in order that the progress of adaptation of the eye during the performance of the test might not be too variable a factor in the result. Average results are in print.[2] Also certain results as to light and color threshold obtained under diminished oxygen during the rebreather test, but these are only stated in percentages based on the total number of cases, in which rise, fall or no change were found; and we are left to guess at the actual number of cases examined, and hence also at the significance of the results stated. The use of the wedge has since been abandoned for reasons which have just been mentioned.

Various letter charts, in which lines of letters are of uniform size, and are in graded degrees of contrast with the background, have also been tried. Notable, among these, is a set included in the work of DeWecker and Masselon, which one of us[3] once attempted to use. It soon appeared, however, that there were greater differences of visibility between the various letters of the same line than there were on the whole between the successive differently contrasting lines.

Nevertheless, since the ordinary Snellen chart, or other letter or character chart, measures minimal size while presenting maximal contrast, it is eminently adapted to estimating such factors as determine the geometric accuracy of the image, namely, the dioptric conditions of the eye, and it is only in a very incidental way, dependent upon the susceptibility of the retina itself to light or light changes. It apparently does not report changes or differences in retinal sensitiveness within the limits of normal function, and in disease of the retina the impairment in visual acuity is generally enormous. In short, with the test letters the retina is "everything or nothing," and it is this fact that leaves it to be desired that some method be devised which actually measures retinal sensitivity, both as to individual differences and as to functional differences within the individual.

The selection of the method used in the work herein described arose from consideration developed in a previous communication, to which the reader is referred for a fuller discussion.[4] Briefly, the plan of using a stimulus of minimal area and of minimal duration has been adopted and followed as the result of the consideration that these experimental conditions closely represent the common and usual conditions of retinal stimulation occurring in the course of ordinary critical eye work, and that these conditions are almost identical with those confronting the aviator or aerial navigator who is on the alert to detect an enemy air craft at the longest possible range. Stated in another way, the method rests upon the use of a stimulus which is within such limits of magnitude, both spatial and temporal, that it may physiologically be considered as being a point and existing for an instant of time, the only

[1] (*a*) Manual of Medical Research Laboratory, Washington, Government Printing Office, 1918, p. 140, and pp. 145, 146; also (*b*) Air Service Medical, same, same, 1919, p. 270, and pp. 275, 276. The text referred to in these two volumes is almost if not quite identical.

[2] Loc, cit., (*a*) pp. 288, 289; (*b*) pp. 158, 159.

[3] Cobb, Psychological Review, XXVI, 1919, p. 447 ff.

[4] Cobb, "The Momentary Character of Ordinary Visual Stimuli." Psychobiology, II, pp. 237 to 244.

implication of this delimitation being the condition that within these limits the product of time and area shall, other things equal, be constant for a given sensory effect. That such a condition may be realized within limits will appear from what follows.

It is to be added, before proceeding with a description of the apparatus, that this method is perfectly applicable to the study of dark adaptation, with, of course, different limitations involving certain essential changes as to dimensions and as to general plan of construction, but without any change whatever as to the principle involved.

But since it is generally, if not universally, accepted that vision at comparatively high intensities of light or "day vision" depends upon organs anatomically distinct from those involved in "night" or "twilight vision" and concerned in dark adaptation, and since it is a fact that the two phases of vision so distinguished have quite different characteristics, it follows that the experimental findings derived from one of these conditions can not be used as a basis of rating with respect to the other.

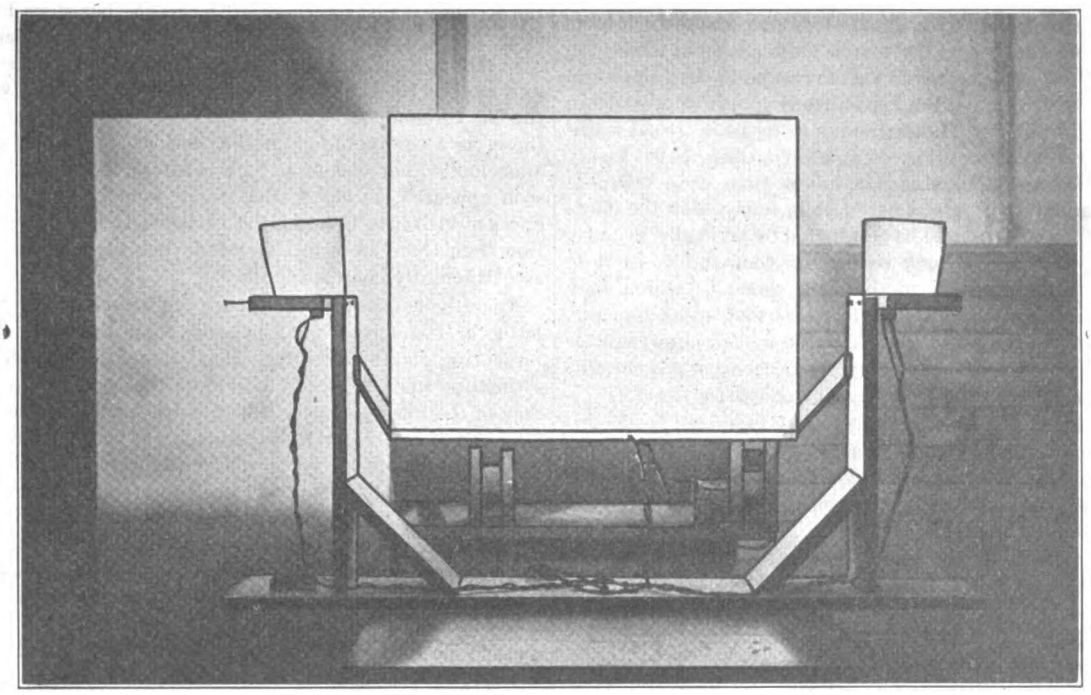

FIG. 1a.

APPARATUS AND METHODS.

The apparatus used in this work consists of an illuminated screen, S, Figure 2, 76 by 60 centimeters, with a small circular aperture at its center. The face of this screen is illuminated by two lamps, as shown in Figure 1a, at the same height as its center, 88 centimeters distant from each other and in a horizontal line 50 centimeters from the plane of the screen. Back of the central aperture and about 30 centimeters distant, is a small screen, S', Figure 2a, illuminated independently by a third lamp, L_3. The three lamps are 6 to 8 volt headlight lamps, vacuum type tungsten filament, the first two rated at 2½ amperes, the third at 2 amperes. The current was supplied by a motor-generator set rated on the generator side, for direct current, at 30 volts, 5 amperes, and at the low voltage used it carried the necessary current (about 6½ amperes) well. The generator being shunt wound, adjustment was effected by means of a rheostat which directly reduced the current in the field magnets, and only secondarily by resistance thrown into the external circuit. Slight fluctuations in the current were prevented by floating a battery of seven Edison alkaline storage cells on the line. (Eight cells would have served better.)

When the brightness of the small back screen is just equal to that of the main screen, the observer, sitting directly before the aperture, is not able to distinguish the latter at all, not even at fairly close range. If an opaque object be now interposed behind the aperture, the latter becomes, in appearance, a black dot. Experimentally, this condition was to be effected for very brief and measurable intervals of time. A gravity drop frame was constructed, indicated at D, Figure 2, and arranged so as to fall a fixed distance, in such a way that the aperture was not covered at any part of the drop, and was hence completely invisible to the subject when the frame alone was dropped. A detachable blind could be fitted into the frame to be carried with it in the fall and to pass behind the aperture, cutting off, during the time of passing, the light which had been reaching the eye of the subject from the back screen. This device was so constructed that the upper edge of the blind passed the aperture exactly at the instant when 115 mm. fall, from the starting point, had been accomplished, the lower edge having covered the aperture a brief interval of time before this. Thus the time of darkening of the aperture depended upon the height of the blind.

The heights of the various blinds were computed to give a geometric series of time intervals corresponding to a series of numerical designations, according to the relation:

$$\text{time} = 200 \times (\tfrac{1}{2})^{N/6}$$

where N is the number of the stimulus and the time is expressed in units of 0.001 second (σ). Thus N, aside from being a convenient numerical designation, has also a definite relation to the time interval, and fractional values of N are intelligible by means of the formula. The stimuli actually used are included in Table I, where the time in σ, and the height of the blind in mm. are associated with the stimulus numbers. Blinds were constructed for all the numbers, but it was found by trial more expeditious to increase the interval between the stimuli of a series, so the even numbers were laid aside.

Two apertures of different diameters were used. These were punched in the exact center of cards 5 by 8 inches (127 by 203 millimeters) and fastened interchangeably at the center of the face of the screen S, especial attention being given to see that the aperture was in the correct relation as to height with the drop frame and laterally with the fixation point. A hole in the body of the screen was, of course, necessary. This was eleven-sixteenths inch (17½ millimeters) in diameter.

The diameters of the two apertures were measured from the cards actually used, twice in each of the four diameters at 45°, by the help of a microscope with a vernier micrometer stage and a micrometer eyepiece. The vernier read to 0.1 millemeters, and the measurements so made checked well with measurements similarly made from a pair of cards punched at the same time with the same punches, but never used. The average diameters were found to be:

	Cards used.	Not used (check).
	Mm.	*Mm.*
A and C....	4.09	4.11
B and D...	4.80	4.78

The corresponding areas are: A and C, 13.138 square millimeters; B and D, 18.096 square millimeters.

In order to show whether sensitivity was appreciably modified by minor differences in the brightness of areas

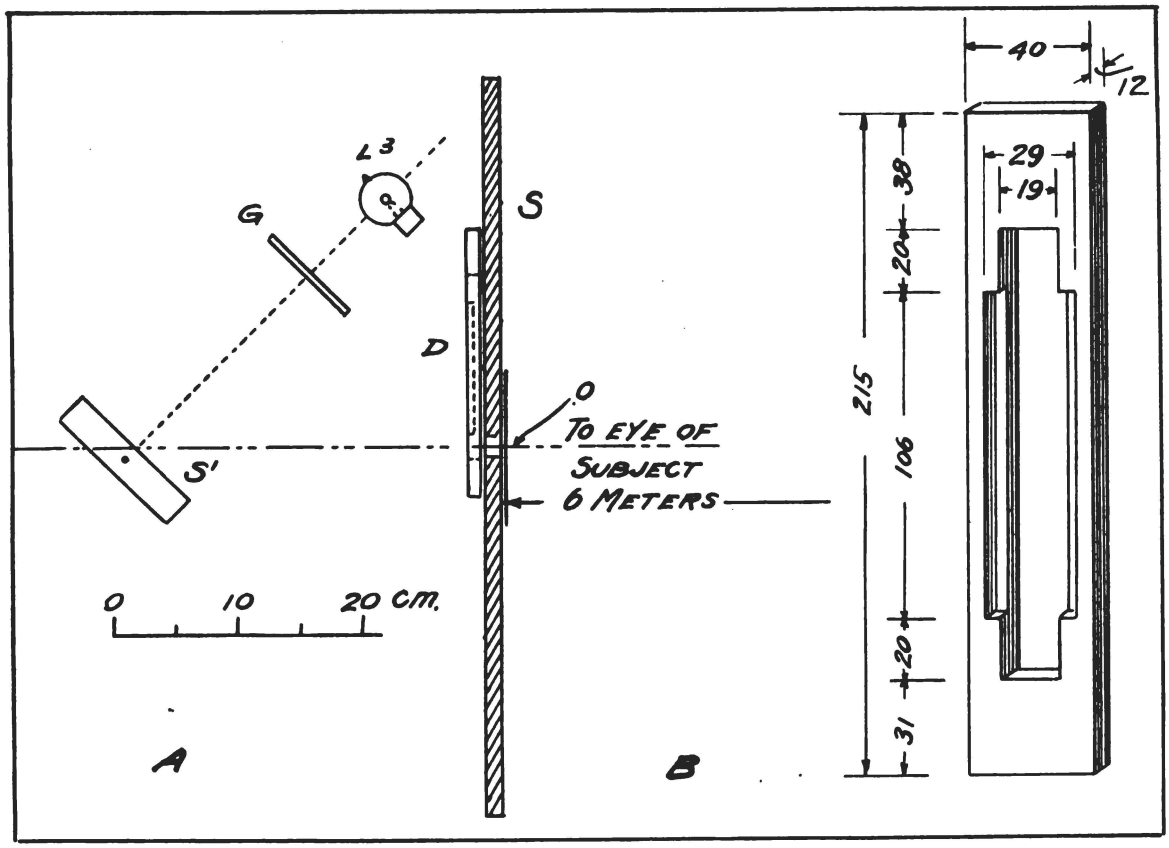

FIG. 2a.

TABLE I.

Stimulus No.	Time.	Width.	Stimulus No.	Time.	Width.
		Mm.			*Mm.*
7.....	109.0	105.4	29.....	16.2	23.1
9.....	91.7	96.5	31.....	13.6	19.6
11.....	77.1	86.7	33.....	11.5	16.6
13.....	64.8	76.7	35.....	9.6	14.0
15.....	54.5	67.2	37.....	8.1	11.9
17.....	45.8	58.4	39.....	6.8	10.0
19.....	38.6	50.6	41.....	5.7	8.4
21.....	32.4	43.5	43.....	4.8	7.1
23.....	27.3	37.3	45.....	4.1	6.0
25.....	22.9	31.9	47.....	3.4	5.1
27.....	19.3	27.1	49.....	2.9	4.3

about the stimulus area, two slips of sheet metal were so placed that by their shadows the light from each of the pair of lamps was cut off from a portion (something less than half) of the main screen nearest to it as indicated in Figure 3a, leaving a central vertical band unshaded, sufficiently wide to make sure that the margin of the aperture was not touched by the shadows. The change in the distribution of light is numerically shown in the figure, which will indicate that the middle and upper parts of the screen were darkened to the extent of 40 to 60 per cent, the lower part only 30 to 50 per cent, of the central brightness. The

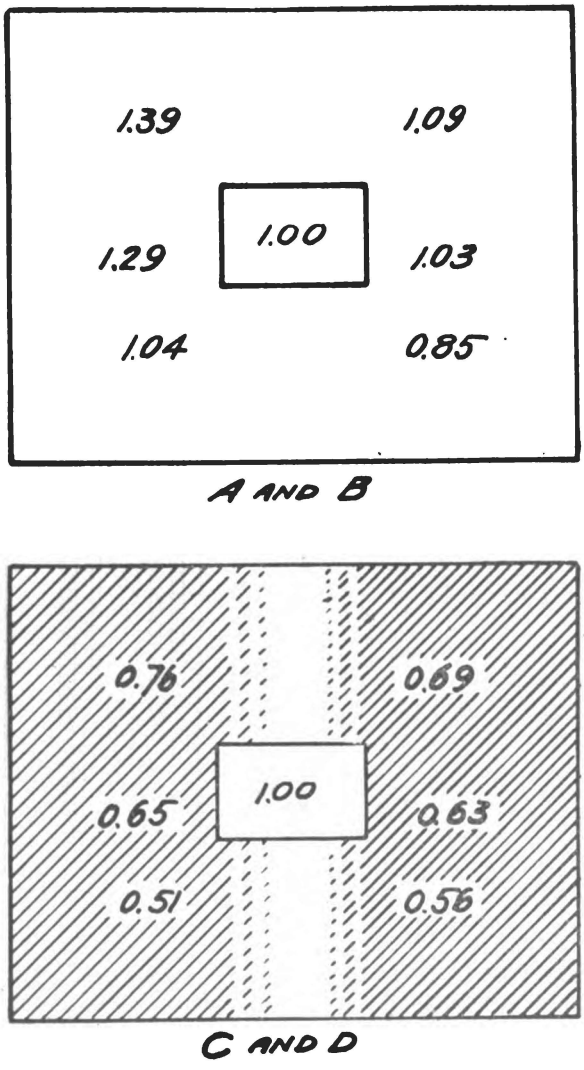

FIG. 3a.

shadows were used in the cases under the heads C and D. The four experimental conditions are thus summarized:

	Aperture.	Shadows.
A.....	Small.....	Absent.
B.....	Large.....	Do.
C.....	Small.....	Present.
D.....	Large.....	Do.

The screen was viewed by the subject at a distance of 6 meters, the position of his head being fixed by a Troland headrest. Fixation was made upon a point on the screen marked by a black-headed tack 21 centimeters (2° in the visual field) directly to the left of the aperture. The subject released the drop frame by touching a telegraphic key conveniently under his hand on the table to which the headrest was clamped. The center of the screen was kept as nearly as possible at a brightness equal to that of the test plate with 3-foot candles (32.3 meter candles) illumination upon it, which was (the reflection coefficient of the plate being 0.722)

$$\frac{32.3\times 0.722}{\pi}=7.42$$

candles per square meter. Readings were taken just before and at the close of each series and their mean was recorded as the exact value for that series. Photometric measurements were made with a Macbeth illuminometer.

PROCEDURE.

The current was adjusted so as to give as nearly as possible the standard photometric brightness at the center of the screen. This was done with the help of the photometer and the actual reading was recorded. The tendency to a slow and progressive change in the current was found to be minimized by so adjusting the rheostats that the battery was discharging into the line at the rate of two or three tenths of an ampere. The back screen was then adjusted to equal the main screen in brightness, i. e., so that the aperture disappeared for the subject. To accomplish this he sat with one eye in the line of experimental vision, the other closed, and at a distance of about 1½ meters, while the experimenter tilted the back screen until the opening was as nearly as possible invisible. If the experience of the subject were inadequate to make this method expedient, the experimenter performed the adjustment himself, and afterwards had the subject pass upon it. The absence of noticeable color difference made this method unobjectionable. The subject then took his place at six meters' distance and the series was begun At the close of the series a second photometric measurement was made and recorded as before. Four such series under conditions A, B, C, and D, in various orders, were run at one sitting and occupied about an hour.

The choice of a psychophysical method to be used in such work as this is largely a matter of excluding theoretically and practically objectionable features, and the discussion of the considerations which led to the choice and adoption of the one here used, and to the present mode of treatment of the results, would be too long to be included in the present communication.

There is comparatively little to be found in the literature upon the method of serial groups,[5] yet in the eyes of one who is interested in psychophysiology rather than in introspective psychology, this has an overwhelming advantage over other psychophysical methods in that it provides an immediate practical check on the subject in requiring him to react differentially to the stimuli and to the associated blanks in the same group.

The groups used consisted of 5 equal stimuli and 5 blanks, presented in shuffled order. For the blanks, in order that

[5] See Stratton, G. M., Psychol. Rev. IX, 1902, pp. 444 to 447, and Thomson, G. H., Br. Jour. Psychol., V, 1912-13, p. 204 ff. and p. 398 ff. Also Myers, A Textbook of Experimental Psychology, London, 1909, p. 209; same, 2d edition, 1911, Part I, pp. 196 to 197.

the motions of the experimenter should not be made the basis of reaction, a small horseshoe-shaped metal device was used to replace the blind, fitting into the drop frame in a similar way, but so formed that at no time during the fall of the drop frame did any part of it intervene between the aperture and the back screen. A fairly large stimulus was used in the first group, the number of the initial stimulus being later determined by previous experience. The subject had only to fixate the designated mark when the signal "ready" was given, release the drop by pressing the telegraphic key, and give his answer "yes" or "no" as to the adjudged momentary presence of the dot. If upon the first group a perfect score were given, the next group, involving a stimulus of one stage shorter duration, was given without pause; otherwise the next longer stimulus until a perfect score was rendered. The first perfect score being the starting point, consecutive groups were presented with stimuli diminishing step by step until a zero (or negative) score was rendered. This completed the series.

The descending order alone was used. The score for a particular stimulus was simply the number of "yes" answers given among the five answers to the stimuli, minus the number of "yes" answers (if any) given among the five answers to the blanks, and could possibly be anything from 5 to −5. Some subjects rarely failed to give correct interpretation to the blanks and rendered a zero score by replying "no" throughout the group. Others showed greater tendency to fail on the blanks and by the method used all were quantitatively "docked" therefor, resulting sometimes, but not frequently, in a score of −1 or −2 at the close of the series. The reason for this mode of rating should be obvious; we have no way of knowing whether the subject sees the stimulus except as we may infer it from the fact that his reaction to it is different from his reaction in the absence of it. We can agree with Myers that the positive reactions to the "catches" are interesting psychologically, but we can not agree with his statement that they are to be left out of account in the computation. The stimulus has been effective only in so far as the positive reactions to it have exceeded the positive reactions to the blank. The negative score is not troublesome if we remember that it is (so to speak) the obvious consequence of bad luck in guessing, and that in the long run this method of computing causes it and other unlucky guesses algebraically to offset the results of lucky guessing not otherwise detectable.

Estimating the threshold from the serial scores was accomplished by determining, by linear interpolation, that value of stimulus in terms of scale number which corresponded with a score of 2½ (50 per cent of a maximum of 5). In cases on inversion, where more than one such point was to be found, the first crossing of the 50 per cent point was interpolated (*a*) reading the series in the descending direction and (*b*) reading the series in the ascending direction. The mean of (*a*) and (*b*) was then accepted as the threshold for that series.

The performance of four series, involving the four conditions A, B, C, and D, occupied about an hour. The order of these was systematically varied from day to day.

The three subjects used are described as follows:

B.—A woman, age about 21, typist. Refraction not determined, but does not wear glasses nor show other evidence of visual defect. An ideal subject, in the fact that she renders prompt and definite judgments.

C.—Captain in the Medical Corps, United States Army, specializing in sense physiology, age 47. Astigmatism, well corrected, and moderate presbyopia. Vision, without glasses R. 20/50, L. 20/50 +. Wears: R: +1.75 cyl. ax. 92½°, V.=20/15; L: −0.25 sph. with +1.75 cyl. ax. 92½°, V.=20/15; with +1.00 sph. each eye, for near vision. As a subject, somewhat slow to react, but with experience in such work.

L.—A woman, age 28, psychologist. Vision 20/20+2/8 each eye. Does not wear glasses. Refraction, without mydriatic: R: +1.00 sph. with +0.25 cyl. ax. 82°, V.= 20/15; L: +0.50 sph. with +0.25 cyl. ax. 112°, V.=20/15. Exophoria, 2 prism diopters at 6 meters. Experienced as a subject in psychological work.

The amount of experience as subject in this identical problem, prior to the work here recorded and incidental to the development of the method, is various for these three. B had about the equivalent of 12 series, C about 30, and L about 20. As nearly all of these were run before the method came into its present form, it is only in a rough way that an equivalent can be estimated.

Before computing the results a few of the series were deleted: (3 in the case of C, 1 in the case of L) where there was suspicion of an error in technic which did not permit of revision, or obvious disturbance of the subject, or, in one case, where the scores of the series gave evidence of some anomalous condition in the subject. In this last it turned out that the inclusion of this value would not have significantly altered the average.

The results of the remaining series were averaged, and in Table II are given: the mean threshold (N) and its probable error (E_N), and the number of terms (series) entering into the mean threshold (p).

TABLE II.

MEAN THRESHOLDS IN UNITS OF STIMULUS SCALE.

Small opening.			Subject.	Large opening.		
N.	E_N.	p.		N.	E_N.	p.
A. No shadows.				B. No shadows.		
22.63	0.32	(18)	B	26.05	0.19	(18)
26.31	.18	(21)	C	29.85	.37	(21)
22.37	.29	(20)	L	26.01	.18	(21)
C. With shadows.				D. With shadows.		
22.79	0.31	(18)	B	27.14	0.21	(18)
26.24	.24	(21)	C	29.17	.27	(22)
22.17	.17	(21)	L	26.96	.18	(21)

(*a*) SAME AS ABOVE. HUGE DEVIATIONS ELIMINATED BY CHAUVENET'S CRITERION.

A. No shadows.				B. No shadows.		
22.63	0.32	(18)	B	26.05	0.19	(18)
26.33	.14	(19)	C	29.85	.37	(21)
22.63	.27	(19)	L	26.18	.17	(20)
C. With shadows.				D. With shadows.		
22.79	0.31	(18)	B	27.32	0.18	(17)
26.05	.22	(20)	C	29.17	.27	(22)
22.17	.17	(21)	L	26.96	.18	(21)

Further, to reach group of results (A, B, C, or D) Chauvenet's criterion was applied, which resulted in further eliminations (1 in the case of B, 3 in the case of C, and 2 in the case of L). The averages from the remaining series are given under (*a*) in Table II.

RESULTS AND DISCUSSION.

The first question to be examined in the light of these results is the hypothesis implied in one of the introductory paragraphs of this paper. In these results, do the threshold times of exposure and the areas of aperture give equal products for the two cases? If it is true that they do, we should find the relation: $a_1t_1=a_2t_2$, or $\frac{a_1}{a_2}=\frac{t_2}{t_1}$, in which a_1 and a_2 are the areas of the two apertures and t_1 and t_2 the corresponding times of threshold exposure experimentally found. But it follows from the formula: $t=200\left(\frac{1}{2}\right)^{N/8}$ that: $\frac{t_2}{t_1}=\left(\frac{1}{2}\right)^{\frac{N_2-N_1}{8}}$, N_1 and N_2 being the two corresponding thresholds as found in terms of the stimulus scale. Hence: $\left(\frac{1}{2}\right)^{\frac{N_2-N_1}{8}}=\frac{a_1}{a_2}=\frac{18.096}{13.138}=1.3773$, from which we obtain, by means of logarithms: $N_1-N_2=3.695$.

This is the difference, on the stimulus-number scale, between the time thresholds for the smaller and larger apertures respectively, which is demanded by the hypothesis that the product, area multiplied by time, shall be constant for the threshold.

How far the experimental results go toward confirming the hypothesis from which the foregoing is, a priori, derived will be seen by a glance at the first three columns of Table III, where the average experimental differences are stated with their respective probable errors. The elimination of the widely deviating results by means of Chauvenet's criterion, it will be seen ((*a*) Table III), has not significantly altered the result. On the average the difference in scale units is 3.77, with a probable error ± 0.14, or (*a*) with application of Chauvenet's criterion, 3.82 ± 0.14. The deviations from 3.695, the a priori value, being, respectively, 0.075 and 0.125, both lying well within the limits of the probable error. It is to be noted that there are items entering into the final average which depart rather widely from the anticipated result. These are under D–C, Table III, the comparison of the two apertures with the shadows on the screen. The departures of the experimental differences from the value 3.695 are here, for the several observers: B, 0.655 ± 0.37; C, -0.765 ± 0.36; L, 1.095 ± 0.25, all of which are seen to be larger than their respective probable errors. In connection with this fact, the further fact is to be noted that the results in the last three columns of the table all indicate that the presence or absence of the shadows was without significant effect, except in the cases under D–B (shadows compared with no shadows, larger aperture) where the differences are too large relatively to their probable errors to be considered insignificant. These differences, further, are all in the same direction as those just pointed out under D–C; each for each, and taken together, the two sets of results might be considered to indicate that the three observers differed most widely from each other in the case of the large aperture with shadows on the screen (condition D), since this is the experimental condition common to the two sets of differences, each of which, in detail, deviates from the general average in a corresponding way. This can be looked upon as presumptive but not as a definite conclusion, since the differences quoted are not large enough to put the matter beyond doubt.

TABLE III.

EXPERIMENTAL DIFFERENCES, IN UNITS OF STIMULUS SCALE.

Large versus small opening.			Subject.	Shadows versus no shadows.		
d.	E_d.	p.		d.	E_d.	p.
B–A. No shadows.				C–A. Small aperture.		
3.42	0.37	9.00	B	0.16	0.44	9.00
3.54	.41	10.50	C	−.07	.30	10.50
3.64	.35	10.24	L	−.20	.34	10.24
3.54	.22	29.74	Mean	−.05	.21	29.74
D–C. With shadows.				D–B. Large aperture.		
4.35	0.37	9.00	B	1.09	0.28	9.00
2.93	.36	10.74	C	−.68	.46	10.74
4.79	.25	10.50	L	.95	.25	10.50
4.00	.19	30.24	Mean	.41	.20	30.24
All results.				All results.		
3.77	0.14	59.98	Mean	0.19	0.14	59.98

(*a*) SAME AS ABOVE. HUGE DEVIATIONS ELIMINATED BY CHAUVENET'S CRITERION.

B–A. No shadows.				C–A. Small aperture.		
3.42	0.37	9.00	B	0.16	0.44	9.00
3.52	.39	9.97	C	−.28	.25	9.74
3.55	.32	9.74	L	−.46	.32	9.97
3.50	.21	28.71	Mean	−.20	.20	28.71
D–C. With shadows.				D–B. Large aperture.		
4.53	0.35	8.74	B	1.27	0.26	8.74
3.12	.34	10.47	C	−.68	.46	10.74
4.79	.25	10.50	L	.78	.24	10.24
4.12	.18	29.71	Mean	.40	.20	29.72
All results.				All results.		
3.82	0.14	58.42	Mean	0.10	0.14	58.43

So far this discussion has been limited to the consideration of the effect upon the time value of the threshold of the two experimental variables purposely introduced. These are the area of the stimulus-opening, and the presence or absence of shadows upon the screen. In addition to these there are three other variables incidental to the experimental procedure, which, including the principal variable, namely, the threshold itself, are listed as follows:

(1) The time threshold. This is the stimulus number reduced, for the purpose of correlation, to an intercomparable value by expressing the result of each series in terms of the mean of the group taken under identical conditions. Symbol, T/M.

(2) The ordinal number of the series in the group of four taken at a sitting.

(3) The ordinal of the sitting in the group of 18 to 22 taken under identical conditions.

(4) The mean photometric brightness of the field immediately surrounding the test-stimulus.

In what follows these quantities are designated by subscripts corresponding to the numerals above.

These four variables are correlated by Pearson's method,[6] two and two, and from the six correlation coefficients of the zero order, so obtained, the partial coefficients of the second order were computed. These, with their probable errors (E_r), are as follows:

Subject.	B		C		L	
	r	E_r	r	E_r	r	E_r
$r_{13.24}$	0.037	0.080	0.098	0.074	−0.362	0.065
$r_{12.34}$	−.046	.080	.082	.074	.125	.074
$r_{14.23}$	.311	.072	.115	.076	.174	.073

Similarly the standard deviations of the four variables of the zero and second orders are:

	B		C		L	
	Zero order.	Second order.	Zero order.	Second order.	Zero order.	Second order.
1	0.065	0.062	0.057	0.056	0.053	0.049
2	1.11	1.07	1.13	1.12	1.12	1.04
3	5.2	5.0	6.4	6.3	6.0	5.9
4	.12	.11	.11	.11	.087	.085

And the characteristic equations derived from these, for the three subjects, are stated as follows:

$$\text{B: } x_1 = 0.002\,x_2 - 0.0006\,x_3 + 0.18\,x_4 \quad E = \pm 0.042$$
$$\text{C: } x_1 = .005\,x_2 + .0007\,x_3 + .06\,x_4 \quad \pm .038$$
$$\text{L: } x_1 = .017\,x_2 + .0010\,x_3 + .10\,x_4 \quad \pm .033$$

In these equations the various x's have reference to differences or variations in the corresponding variables—or perhaps better, we may say that x represents the deviation of the variable from the mean of all its experimentally measured values in units the same as those in which the corresponding quantity is expressed.

If we wish to estimate the extent to which x_1 is influenced by the deviation of any one of the other variables, say x_2, from its mean value, we must substitute that deviation of x_2 for x_2 in the equation and put x_3 and x_4 equal to zero. From inspection of the equations, it will thus appear that x_2 is most significant in the case of subject L. An idea of its importance in these results may be gained by substituting for x_2 its standard deviation (1.12) and we have $x_1 = -0.017 \times 1.12 = -0.019$. Which is to say that in this case fluctuations in the value of T/M (x_1) are introduced by the fact that subject L gave higher results early in the experimental sessions and vice versa, and that the effect of these fluctuations upon her results are represented by a standard deviation of T/M equal to 0.019. This is equivalent to 0.42 or 0.50 in "Stimulus number" (Table I) according as we refer it to the threshold obtained with the small opening (average 22.27, Table II) or the large opening (average 26.48). A representative range of fluctuation due to this cause might be taken as twice this or roughly one number on the scale, if we look upon the fluctuations as centering at the mean, and characteristically extending by an amount equal on the whole to the standard deviation in either direction therefrom. When we investigate in the same way the serial number of the day, the same subject shows the largest deviation: $0.0010 \times 6.0 \times 2 = 0.012$, indicating that the representative practice effect for the whole period of experimentation is small, less than one-third of one scale unit. This is, perhaps, not surprising, in view of the fact that each of the three subjects had had practice with the method before any of these recorded results were taken.

The deviations of the photometric value of the test field, x_4, have not, except in one case, produced any noteworthy disturbance in this work, but such disturbance as is shown, taken together with other considerations, makes the photometric control of the conditions a precaution carefully to be considered. From the characteristic equations, we have, similarly to the foregoing, the disturbance due to photometric fluctuation:

	In terms of T/M.	In scale units.
For B, 0.18× 0.12 ×2−	0.043	0.97 to 1.14
C, .06× .11 ×2−	.013	.34 to .38
L, .10× .087 ×2−	.017	.38 to .45

While, in scale units, these deviations are not larger than the deviations due to variables 2 and 3, i. e., those defining the place of the series in the experimental order, it must be emphasized, first, that the variations in the photometric values themselves (x_4) are small, being no more than the unavoidable variations in the adjustment of the apparatus to an exact value, but they are still large enough to measure. The largest value of the standard deviation is 0.12 apparent foot candles (in the cases of B and C), which means that while 3 apparent foot candles was the brightness aimed at, the actual brightness fell about as often within the limits 2.92 to 3.08 ($3.00 \pm 0.6745 \times 0.12$) as it fell outside of these limits. These limits are the exact value attempted, plus and minus its probable error computed from the actual results.

The second point to be emphasized is, that if this measure of retinal sensitivity is to be used as a test, the apparatus must be checked against a standard light-source, by means of a photometer, and corrected as often as necessary as the work proceeds. The mean coefficient of x_4 in the three characteristic equations is 0.11 and the corresponding coefficients of correlation (14.23) are large enough to be significant. This means that within the present limited range of the actual photometric settings, the measure of sensitivity of the individual changed at the rate of 11 per cent (1½ to 3 numbers in the various cases) per apparent foot candle. While it is not correct to extend the application of this rate of change beyond the range for which it was actually found to exist, it must nevertheless be remembered that the voltage in the usual lighting circuits is often a highly variable quantity; that the percentage change of the candle-power of an electric lamp is several times the corresponding percentage change in

[6] As described by Davenport, C. B., Statistical Methods, 3d ed. New York, p. 44. The mathematics involved in the discussion is treated by Yule, G. U., Theory of Statistics, London, 1919, chap. 12.

voltage; and that an individual lamp operated at its rated voltage is a changing and not a constant source. Such amps are usually designed and rated to operate 1,000 hours with 20 per cent drop in candle power during that period. Twenty per cent of the present screen brightness is 0.6 apparent foot-candles, which would, on the average, condition a drop of 0.066 in T/M, or a drop of nearly 2 scale-units in retinal sensitivity. And this is nothing as compared with the errors that would have been introduced by depending upon a line-voltage characterized by such fluctuations as those existing at Mitchel Field at the time this work was done.

Another consideration, which led to the installation of the motor-generator and battery used in the present work, was the possibility of errors due to the use of the alternating current. Although ordinarily appearing to give a steady light, electric lamps, and especially those of the lower wattages and therefore more slender filaments, undergo rapid fluctuations in candle power synchronously with the alterations of the current. On a 60-cycle current the dim (or bright) phases occur at the rate of 120 per second, or at intervals of 8.3σ. Stimulus No. 22 has a duration of 29.7σ, No. 29, 16.2σ. It seemed clear in advance, that the fluctuations in the light from a lamp on the alternating circuit might introduce errors, variable in amount according to the exact phase of the current in which the shutter was dropped. The use of the direct current evaded this dubious condition; and the use of automobile lamps, designed for low voltage and high current, and consequently having filaments too coarse to readily follow, in temperature, any sudden and slight fluctuations of the current, was especially favorable from this standpoint.

SUMMARY.

1. A threshold method of measuring retinal sensitivity is proposed, by which a stimulus of very small and fixed extent is exposed for a very short measured time. The stimulus is physically a negative one, by which is meant that it appears as a black dot upon a white screen.

2. The psychophysical method of serial groups was used, each series of groups furnishing one datum. The basis of the conclusions is 240 such series, about equally divided among the three subjects.

3. It was found that the product of the time of exposure multiplied by the area of the stimulus was constant on the average at the threshold. This applies to the two apertures used, of 13.138 and 18.096 square millimeters area respectively, observed at 6 meters distance.

4. For the several observers the average threshold time, reduced to its equivalent with a standard opening (area= $10\sqrt{2}$ square millimeters), was found to be: B, 25.7 σ; C, 19.5 σ; and L, 26.2 σ.

5. Shadows covering the major part of the screen, but not the working area immediately about the stimulus, by which 40 to 60 per cent of the light was cut off, did not significantly alter the time necessary for effective stimulation.

6. The place of the series in the succession of the usual four run at one session did not appear, except in one case, to be of significant effect upon the threshold time. The correlations were dubious in the other two cases. In the one case in question, a manifest hyperopia of one diopter and of one-half diopter was demonstrable in the two eyes respectively, and sensitivity appeared to grow less during the progress of the day's series.

7. The serial place of the day in the whole course of experimentation was of negligible import, except possibly in the case of the same observer, where the coefficient of correlation (second order) was 0.125 ± 0.074, and no more than a minor effect upon the result was indicated.

8. There appeared to be a fairly definite and constant correlation between the threshold time and the unavoidable but measurable variations in the photometric brightness of the screen in the direction of decreased threshold time with increased brightness. This was minimized in the experimental work by careful measurement and adjustment of the brightness. This result justifies the photometric precautions used and indicates the absolute necessity of careful photometric control in any application of this method of retinal sensitivity measurement.

EXPLANATION OF TABLES.

TABLE I.—The arbitrary scale of stimuli (stimulus number), the duration of each (time, σ), and the vertical length (width, mm.) of the corresponding blind calculated to conclude the required period of time just as the drop frame has completed 115 millimeters of free fall.

TABLE II.—The average results, for each of the three subjects. The small opening has an area of 13.138 square millimeters, the large one 18.096 square millimeters, both seen at 6 meters distance, at the center of a white screen 60 by 76 centimeters, fixation 2° to the left of the (central) opening.

N.—Average threshold, arbitrary scale. Compare Table I.

E_n.—Probable error of the same.

p.—The number of series upon which the above are based.

TABLE III.—The differences on the arbitrary scale, due to the use of the large or small opening and those due to the presence or absence of shadows. Compare Table II.

d.—Experimental difference, arbitrary scale.

E_d.—Probable error of the same.

p.—Weight of the result, the weight of a single series being unity.

LEGENDS TO FIGURES.

FIG. 1.—General view of the apparatus, about as seen by the subject.

FIG. 2.—A, diagram of the apparatus; B, detail of the drop frame (D), with dimensions in millimeters.

FIG. 3.—The relative photometric brightness at various points on the screen, and the distribution of the shadows in cases C and D.

—By courtesy of the Journal of Experimental Psychology.

INDIVIDUAL VARIATIONS IN RETINAL SENSITIVITY, AND THEIR CORRELATION WITH OPHTHALMOLOGIC FINDINGS.

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The method by which the measurements of retinal sensitivity were made, which are the subject of this communication, has in its essential details already been described.[1] The purpose of the present paper is to investigate primarily the significance of the results obtained by the method, and secondarily its applicability as a test in the routine examination of candidates for flying status in the Air Service. Measurements were made upon a group of 101 subjects. Visual acuity was measured in nearly all of these for each eye separately and for both eyes together by means of the Snellen letters under the actual conditions of the experiment; and in addition, the complete findings of the routine ophthalmological examination for flying status upon 59 of these subjects for the purpose of comparison.

The group consisted of such individuals as were available, and without specific enumeration may be described by noting the classes into which they might be grouped, in the order of their relative numbers: (1) Enlisted men of the Army, a few from the Navy, some recruits and some civil candidates for the cadet school of aviation; (2) a number of flying officers; (3) a number of other officers, chiefly of the medical corps of the staff of the Medical Research Laboratory or there present for instruction; (4) a few civil employees of the laboratory (including four women), technical, clinical, and one skilled mechanic.

The present method of estimating retinal sensitivity is, essentially, to determine the duration of exposure of a black dot at the center of a white screen, necessary in order that the dot may just be seen. The actual dimensions of the dot and the distance of the subject from the screen are kept constant, as is also the photometric brightness of the screen. The dot is formed by a small circular aperture in the screen, through which a secondary screen, behind the other, is seen, and the screen behind is so illuminated that its appearance is an exact match with the margins of the aperture. When this is accomplished the aperture disappears. It becomes in appearance a black dot when an opaque object cuts off the light coming through it, and the necessary time of darkening, in order that the dot may be perceived with 50 per cent certainty, is the quantity measured.

[1] Cobb and Loring, Jour. Exp. Psych. 1921.

The usefulness of a new test may depend upon one of two circumstances. It may be supplementary to tests already in use (*a*) in a confirmatory sense, or (*b*) it may measure something not already taken into account by tests currently used. It may be useful in either case. Intrinsically, a test must show, by the results that it gives—(*c*) that it actually does give a measure of something worth knowing, and (*d*) it must give a fairly reliable result. This last (*d*) has been accomplished, if measurements on the same individual, under conditions as nearly the same as practical considerations warrant, will, at different times, give not too widely divergent results. The condition (*c*) is met (granting that we aim to test individuals) if results from different individuals prove to be different by variations of a larger order of magnitude than the variations in the same individual under identical conditions. If we aim to detect changes in the sensitivity of the individual, the condition (*c*) will have to be met somewhat differently.

The first point to investigate is the reproducibility of the result. It was shown in the previous communication upon this method, that for the three subjects, each having had some practice as such, the variability of the result of a single series, representing about fifteen minutes' expenditure of time, was represented by a probable error of one unit or less on the arbitrary scale, equivalent to not more than about 8 or 9 per cent in actual time. [2] The figures are given here in Table I.

(2). The relation between T (stimulus number) and t, the time of exposure (thousandths of a second), is given by the formula: $t = 200\ (\frac{1}{4})^{T/8}$. An extract from the original table embodying this relation is given here:

T.	Time.	T.	Time.	T.	Time.	T.	Time.
20	35.4	22	29.7	24	25.0	26	21.0
21	32.4	23	27.3	25	22.9	27	19.3

From these can be obtained the time values corresponding to the other numbers, if we remember that an increase of 8 units in T means that the time is divided by 2 and vice versa.

Furthermore, owing to the fact that the screen opening (area, 14.421 square millimeters) was somewhat different from its designed size (10.2 square millimeters) a slight correction is necessary to reduce the values for the group of subjects treated in this paper to standard conditions. This correction (to be perhaps unnecessarily accurate) consists in decreasing T by 0.22; or increasing the time by 2 per cent.

TABLE I.

Subject.	T.	s T/M.	E.	Time thousandths.	
				Mean.	Limits of P. E.
B.....	23.70	0.062	0.99	25.7	23.6 to 27.9
C.....	26.85	.056	1.01	19.5	17.9 to 21.3
L.....	23.48	.049	.78	26.2	24.5 to 28.0

This would be considered good reproducibility for such work as the present. But it must be remembered that these subjects were all more or less practiced in the method before the above results were obtained.

Before considering the results of the group, it may be well to examine the measurements taken from the above three subjects in another respect. The question arises in connection with a test of this sort, not only what will happen when a measurement is attempted upon a new and unpracticed subject, but also what happens in the case of any subject, practiced or not, when several series are run in succession. There is the possibility of a fatigue effect, or of an effect of learning or practice. These two may be expected to affect the result in opposite ways and may predominate, one or the other, irregularly, or may possibly tend to offset each other.

The average results for the three subjects first discussed follow, accompanied by the number of items entering into the average and by the mean variation. The average values (M) are all in the neighborhood of unity, because, for the purpose of comparison, each item was, before averaging, divided by the mean of all results (T) for identical physical conditions. The figures given, both threshold and mean variation, are therefore expressed in terms of the general mean. Similar results for a group of 33 unpracticed subjects (the first of a group of 96 subsequently to be discussed) appear in the fourth line. Here each item has been reduced to the average of the individual's four consecutive series as unity.

TABLE II.

Subject.	Series 1.			Series 2.			Series. 3.			Series 4.		
	N.	M.	MV.	N.	M.	MV.	N.	M.	MV.	N.	M.	MV.
B.....	18	0.996	0.048	18	1.002	0.069	18	1.003	0.049	18	0.993	0.037
C.....	22	.985	.057	22	.998	.058	22	1.005	.042	22	1.012	.046
L.....	21	1.016	.058	21	1.020	.036	21	.981	.042	21	.964	.030
Various.....	33	.993	.044	33	.992	.046	33	1.019	.054	33	.996	.050

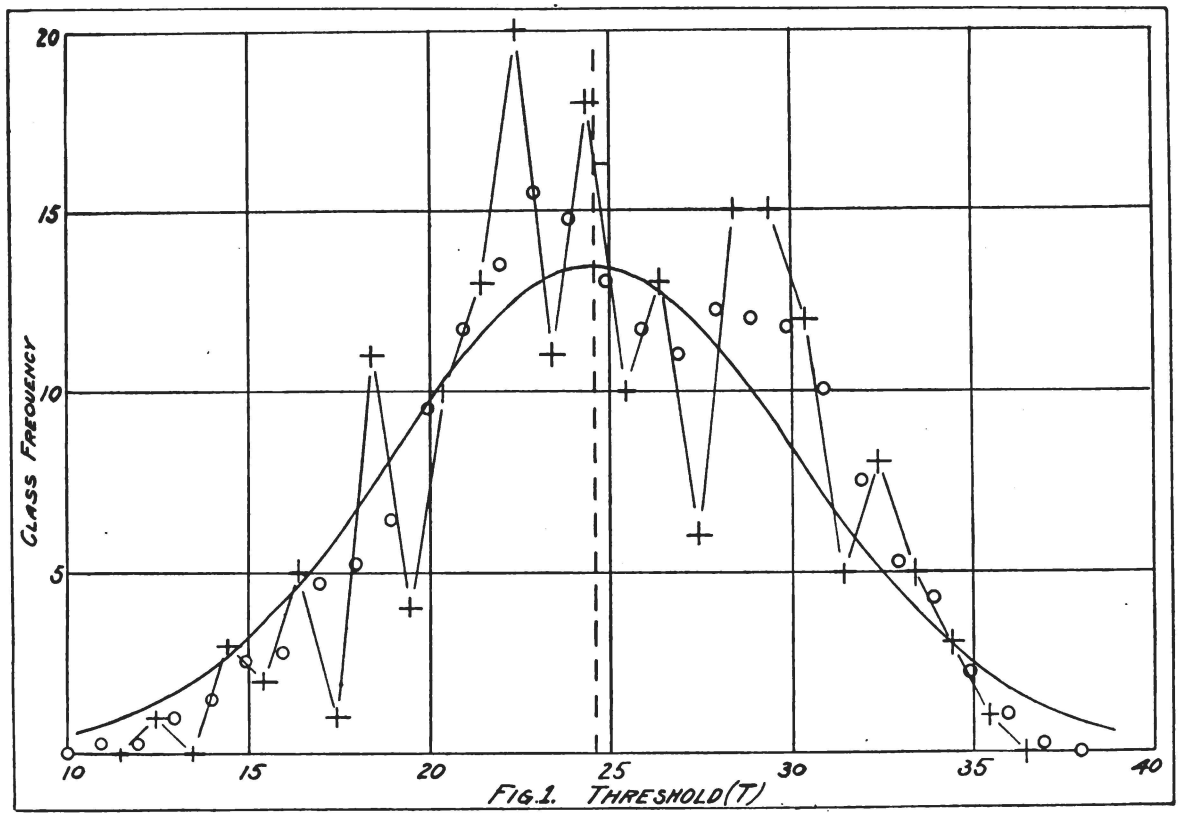


FIG. 1. THRESHOLD (T)

It will appear from the above that on the whole the variabilities of the successive results diminish somewhat, although in the case of the unpracticed subjects the change is in the opposite direction, but not to a significant extent. It appeared, however, that it would be out of the question, in using the method as a test, to expend the time necessary to run four or even three series as a routine matter. That consideration will therefore be dropped, and only the first and second series will be considered in what follows.

The 33 subjects just mentioned were the first of a series of 101, which will form the basis of the major part of this discussion. Visual acuity was taken, at the time of the retinal sensitivity measurement, in 100 of these with each eye separately, and in 91 of these, with both eyes together. Unfortunately, in 5 cases of the 91, retinal sensitivity proved to be too low to measure with the apparatus as constructed, and rather than deviate from the established technique, it was decided to record these simply as "too low to measure." Some idea of the probabilities in these five cases may be gained from the fact that the lowest measurement actually made in conformity with the established technique was T = 12.7, and the three next 14.3, 14.5, and 14.7, respectively.

The distribution of 192 measurements, two upon each of 96 subjects, is shown in Figure 1. The small circles represent values of the "sliding" averages of four of the original class-frequencies and the smooth curve is that of a normal distribution based upon characteristics of distribution derived as follows: (1) A mean drawn from the whole of the 192 measurements less the 10 highest, omitted to offset the absence of the corresponding 10 lowest of 202 possible measurements, which are not included in the 192 because of their being too low to measure; and (2) a measure of dispersion derived from the sum of the deviations of that fraction of the distribution lying above the mean.

The first of the curves in the diagram (a) exhibits irregularities due to the method of interpolation by which a numerical threshold was derived from the results of one series. This method favored the even integers; that is, of the 192 interpolated values, 119 were even integers plus a fraction, and 73 only were odd integers plus a fraction. Inspection of the figure will show this irregularity. However, the circles representing the average frequency of four consecutive classes, plotted against the average of the corresponding four class-types, represent values from which this systematic irregularity is eliminated, and among which other irregularities are also, in part, evened out. Nevertheless, in comparing the line of the circles with the curve of normal distribution, it would appear that there are in the former two maxima: one at about the point where T=23, ($t=27\sigma$) another at T=29, ($t=16\sigma$); with a minimum between them T=27, ($t=19\sigma$). In other words, the plot suggests very strongly that the distribution of results is a bimodal one.

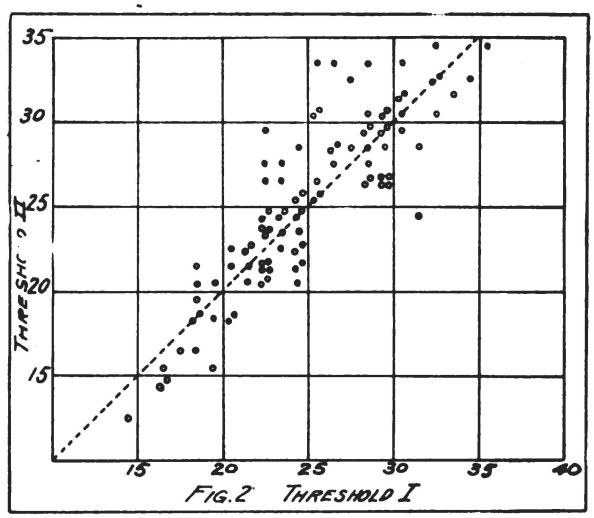
The relation existing between the results of the first and second series on each of the 96 subjects is shown in Figure 2, where the second of these is plotted directly against the first. The two means are I, 24.91 and II, 25.17; very close together. The oblique dotted line, drawn at 45° inclination, is the locus of the cases in which the two are exactly equal. The mean values just stated would indicate a tendency in the subjects to go higher on the second series, and a glance at the figure will show this tendency in general to be greater in those above the mean than in those below it and, in fact, to be reversed in a few cases at the other extreme. This shows itself also in the two standard deviations. That for the first series is 4.6, for the second 5.1. The correlation ratio is 0.857 ± 0.018.

The characteristic equations derived from the above are:

$$x_1 = 0.77x_2,\ E_1 = 1.6;\ \text{and}$$

$$x_2 = 0.96x_1,\ E_2 = 1.8,$$

in which the two probable errors (E) may be taken as an index of the variability of these inexperienced subjects, as a group, for the first and second consecutive trials, respectively. This indicates a lower degree of reproducibility for the group of 96 subjects than for the three considered in Table I. There the values for E are of the order of 1 or less. The group of 33 various observers will be seen to compare very favorably with the three observers, B, C, and L (Table II, M'V's).[3] They therefore appear to show a better reproducibility than the group of 96 as a whole, of which they are a part.



This is incidental to the rather unusual way in which the method of correlation[4] has here been applied, for the purpose of estimating from the results of a group the expected standard deviation of repeated identical measurements upon an individual. In plotting the second set of results, b, against the first (a) as abscissæ, it will be seen that although the a's are of identical class type for any column of b's, yet in the case of any pair plotted in the column, the a is still in every case a variate from a possible mean, from which it deviates on the whole by an amount represented by its own standard deviation. Thus the standard deviation from their characteristic line of the b's ($\sigma_{2.1} = \sigma_2\sqrt{1-r^2_{12}}$) is not the standard deviation to be expected of repeated identical measurements, but is greater than the latter, as the standard deviation of a (sum or) difference exceeds that of either term; by the factor $\sqrt{2}$ when the two are of equal variability. Accordingly the two E's stated above should be divided by $\sqrt{2}$, and they then become $E_1 = 1.1$, $E_2 = 1.3$, which conform fairly well to the results stated in Tables I and II.

[3] The probable error for all results of the group of 33, Table II is 1.05, on the same basis as the values for E in Table I, for subjects B, C, and L.

[4] The correlations discussed here were performed by Pearson's method.

Of especial interest in determining the value of this test is the question of the correlation existing between its results and those of the ophthalmologic tests. And of these the relation with visual acuity taken by the Snellen letters was of especial interest. Visual acuity was taken for each eye separately and for binocular vision by hanging a test letter card upon the screen of the apparatus, so that the conditions of the retinal sensitivity test were exactly reproduced for the letter test. The results of the correlations performed by Pearson's method are given in Table III.

TABLE III.

(*a*) Numerical designations of the variables:

1. Retinal sensitivity (mean of I and II series).
2. Visual acuity (Suellen), binocular vision.
3. Same, better eye alone.
4. Same, poorer eye alone.

(*b*) Correlation-ratios:

ss.	N.	r, zero order.	E_r.	ss.	r, first order.	ss.	r, second order.
12	86	0.375	0.062	.....	.....	12.34	0.177
13	95	.321	.062	.....	.....	13.24	−.068
14	95	.355	.060	.....	.....	14.23	.147
23	91	.871	.017	23.4	0.716	23.14	.716
24	91	.723	.034	24.3	.191	24.13	.160
34	100	.760	.029	34.2	.384	34.12	.389

(*c*) Standard deviations:

ss.	N.	σ, zero order.	ss.	σ, second order.	ss.	σ, third order.
1	95	4.62	.....	.....	1.234	4.24
2	91	.271	2.34	0.131	2.134	.129
3	100	.275	3.24	.125	3.124	.125
4	100	.247	4.23	.157	4.123	.155

An incidental question, worked out by way of side issue, is the relation of binocluar visual acuity (V_0) to the two values of monocular visual acuity obtained with the better eye, (V_1) and the poorer eye (V_2) respectively. The equation for this value, derived from the correlation-ratios of the first order and the standard deviations of the second order, involving the variables 2, 3, and 4 only, is as follows:

$$V_0=0.75\ V_1+0.16\ V_2+0.18 \qquad (1)$$

the standard deviation of V_0 is $\sigma 2.34=0.13$. It is to be remembered that the bulk of the results fell about the region of V=20/30 to V=20/15 (6/9 to 6/4.5 metric or 1 to 1.33 decimal) and the application of this equation is not safely to be extended outside these limits.

The interpretation of a characteristic equation such as the above is that V_0, calculated from the observed values of V_1 and V_2, is the expected value of binocular acuity, and that experimentally determined values may be expected to deviate from this as implied in the accompanying standard deviation, $\sigma 2.34=0.13$.

Similarly, the characteristic relation between retinal sensitivity (T) and the three values of visual acuity above enumerated is:

$$T=5.8\ V_0-2.3\ V_1+4.0\ V_2+16.2 \qquad (2)$$

and the standard deviation of T is $\sigma 1.234=4.24$; the same reservations as to the limits of applicability of this equation to apply, as in the case of equation (1).

These relations exhibit one or two points worthy of note. From equation (1), it will be noted that binocular visual acuity depends in a major degree upon the vision of the better eye. Whether it depends at all upon the vision of the inferior eye is an important question. V_2 being ordinarily somewhere about unity, the value of the V_2 term will be about 0.16, which is not greatly in excess of the standard deviation of V_0 from its value computed by the equation. However, while the plotted results show many cases where binocular vision was distinctly better than the vision of the better eye alone, there are but 4 cases in a total of 91 where the reverse is true, and this only to the extent of one class interval, equal to two single letters on the chart, or decimally expressed, equal to a difference of from 0.04 to 0.15 according to the portion of the chart involved. The mean value for V_0 is 1.22; for V_1, 1.16; and for V_2, 1.06; which also would indicate a definite extent to which, on the average, vision of the one eye is helped by the second, inferior, eye in binocular vision.

As to equation (2), the negative coefficient of V_1 would seem to indicate that the better eye has a negative contributory value to retinal sensitivity. By the same reasoning as the foregoing we see that in general the amount of the second term, V_1 being about unity, does not exceed the standard deviation of T (4.24). We must also bear in mind that the three V's bear high correlations, each to the other. The writer would interpret the equation as meaning that the better eye contributed to the result in the case of retinal sensitivity (that is, reinforced the poorer eye) only in so far as it does the same with reference to the letter chart; that is, only in so far as it cooperates with its inferior fellow in other respects. Retinal sensitivity is shown by the equations to be more highly dependent upon V_0 than upon either V_1 or V_2; which is perhaps to be expected, for retinal sensitivity was also taken binocularly.

This equation answers the question as to whether this test is to be looked upon (as indicated in an early paragraph of this paper) as supplementary to other tests in (*a*) a confirmatory sense or (*b*) as measuring something not already taken into account.

For the measures of retinal sensitivity in the 95 cases taken into account in the correlations, the standard deviation (σ) is 4.64. Equation (2) should give for T the closest value possible to compute from all the data on visual acuity. The variations of the actual measurements from this computed value are represented by $\sigma 1.234$, following equation (2), and equal to 4.24. Thus the attempt to express retinal sensitivity in terms of visual acuity is futile. It still deviates in much the same degree from the computed values, and we must conclude that retinal sensitivity, measured by the present method, involves a new characteristic of vision that is not to any significant extent taken into account in the measurement of visual acuity by means of the letter chart.

In examining the relation of the retinal sensitivity results to the ophthalmologic findings as a whole, it was necessary to establish some reasonable means of numerical rating as to the latter. The ophthalmologic examination, of which the results were used, was part of the general medical examination of candidates for flying status, known at the Medical Research Laboratory as "609," from the form number of the blank used to record the results. The criteria

of ophthalmologic qualification, as practiced at the time this work was done, are here reproduced. The method of rating, as will be seen, was to score 1 against the candidate for a contingent disqualification, as implied in the following, paragraphs 3, 5, 8, and 9; to score 2 for disqualification in one particular; and to score 1 for each further point of disqualification. The rules following were interpreted literally. Following each paragraph, in parenthesis, are stated such supplementations and changes as were necessary to make the rating just and unequivocal, or to explain the nature of the test to one unfamiliar with the special practice.

1. *Visual acuity.*—The minimal visional requirement for each eye is 20/20. If two or three letters are not read in the 20/20 line, they may be offset by an equal number of letters read in the 20/15 line.

(The ratings taken in the experimental room were used, not those furnished by the opthalmologist. In view of the qualification in the foregoing paragraph, a subject was passed if he read 20/20 less two letters, assuming in the absence of record of the fact, that he was able to offset these by two read in the 20/15 line. The decimal value 0.92 or over satisfied this condition.)

2. *Depth perception at 6 meters.*—An average depth difference of more than 30 mm. disqualifies the applicant.

(Two rods, 1 cm. in diameter, separated 6 cm. laterally, must not be more than 30 mm. apart in the direction of vision when set to apparent equidistance by the candidate. The rods were seen in silhouette against a bright background, and seen through an opening which did not permit vision of either top or bottom of the rods.)

3. *Maddox rod screen test at 6 meters.*—Esophoria of more than 4△ is a disqualifying factor if associated with less than 4△ of prism divergence, or if associated with diplopia in the lateral positions on the tangent curtain, or if associated with an amount of accommodation near the lower limits, or if associated with an amount of hyperopia near the disqualifying limit.

4. Esophoria of more than 10△ is a disqualifying factor, even if unassociated with any of the preceding conditions.

5. Exophoria of more than 2△ is a disqualifying factor if associated with an angle of convergence near the disqualifying limit, or if associated with diplopia in the lateral positions on the tangent curtain.

6. Exophoria of more than 5△ is a disqualifying factor even if unassociated with any of the preceding conditions.

7. Hyperphoria of more than ½△ disqualifies the applicant without further supporting evidence.

8. *Maddox rod screen test at 33 cm.*—Exophoria of 4△ may be considered the normal condition. Any considerable variation from this condition is to be interpreted in connection with the other associated tests. An exophoria of more than 12△ at 33 cm. disqualifies.

(1 to 7△ exophoria at 33 cm. were taken as the normal condition. Outside of these limits a question was scored.)

9. *Prism divergence.*—Prism divergence of more than 9△ disqualifies the applicant if associated with an angle of convergence near the disqualifying limit. If less than 4△ of prism divergence is found associated with more than 4△ of esophoria at 6 meters, the applicant is disqualified.

(These grades of muscle abnormality which do not disqualify except contingently upon some other finding were marked with a question. One or more questions in the absence of final disqualification scored 1 only against the applicant.)

10. Prism divergence of more than 15△ disqualifies without further supporting evidence. Prism divergence of less than 2△ disqualifies without further evidence.

11. *Test of associated parallel movements.*—The applicant is disqualified if the underaction or overaction of any of the extrinsic ocular muscles causes diplopia except in the extreme positions, where a small separation of the images may be disregarded. Nystagmus disqualifies if it is demonstrated except in extreme positions.

12. *Inspection of the eyes.*—Any pathological condition which may become worse or interfere with the proper functioning of the eyes under the fatigue and exposure of flying disqualifies the applicant.

13. *Accommodation.*—Accommodation is normal if it lies between limits 2 diopters above and below the mean for the applicant's age. Failure to read within these limits disqualifies.

Table of mean values of accommodation power.

Age.	Dptrs.	Age.	Dptrs.	Age.	Dptrs.	Age.	Dptrs.
18	11.9	25	10.2	31	8.6	37	6.8
19	11.7	26	9.9	32	8.3	38	6.5
20	11.5	27	9.6	33	8.0	39	6.2
21	11.2	28	9.4	34	7.7	40	5.9
22	10.9	29	9.2	35	7.3	45	3.7
23	10.6	30	8.9	36	7.1	50	2.0
24	10.4						

14. *Angle of convergence.*—An angle of convergence smaller than 40° disqualifies.

15. *Central color vision.*—If it is apparent that mistakes made by the applicant are due to color confusion and not to carelessness or failure to understand instructions, he is disqualified.

(Color vision was left out of consideration in grading the subjects. There were but three cases not definitely found normal as to central color vision as follows: (1) No record as to color vision, record otherwise incomplete, and subject therefore excluded from consideration; (2) no record as to color vision, disqualified on account of visual acuity and hyperphoria; (3) found to confuse reds and greens. No other disqualification or question.)

16. *Field of vision for form and color.*—The normal visual field for form is largest; those for blue, red, and green are successively smaller in the order given. The color fields should be nearly concentric with the form field. Any marked contraction of the form field disqualifies the applicant for flying.

17. *Refraction.*—The applicant is disqualified if he can not read 20/20 without more than one diopter of correction, either hyperopic, myopic, or astigmatic.

Concerning paragraphs 11, 12, and 16, it was assumed that no disqualification existed unless specified. The records furnished the writer did not ordinarily state the findings on these points.

Of a total of 101 subjects upon whom retinal sensitivity measurements were made, there were 59 with records complete as indicated above, and only these are included in what follows.

It will be seen from the plot (fig. 3a) that those showing the highest number of points as to opththalmologic defects have, in general a low retinal sensitivity; curve *b* shows the average number of points of defect for each class as to

retinal sensitivity; and curve *d* the average retinal sensitivity for each particular score. Both of these curves bear out the first statement made. The correlation ratio is -0.444 with a probable error of ± 0.070.

If, however, we exclude those having an ophthalmologic score of 4 or more against them, we get a correlation ratio of 0.009 ± 0.094, which is no correlation at all. The curve (*c*, fig. 3b) shows that there is no significant relation between retinal sensitivity and the ophthalmologic findings when those defective with a score of 4 or more are excluded.

We must conclude, therefore, that there is no relation between the defects elicited by the ordinary ophthalmologic examination on the one hand, and the present retinal sensitivity rating on the other; excepting those cases in which the clinical defects are comparatively numerous, in which these are signs of some rather general, perhaps distinctly pathological, derangement of the visual organs which comes to be generally reflected in their various functions, of which retinal sensitivity is one.

This conclusion will perhaps be borne out by inspection of the following synopsis of all results in the 59 cases considered. Where retinal sensitivity was too low to measure this is indicated by the word "low" in place of the numerical result. Otherwise the synopsis should be self-explanatory:

Summary of cases.

Serial No.	Retinal sensitivity.	Clinical description.		Number of cases.
.....	.....	Unquestioned, score 0		16
.....	.....	Questioned, score 1:		
.....	.....	Esophoria	5	
.....	.....	Exophoria	22	
.....	.....	High prism divergence	7	
			34	
.....	.....	Counted twice or more, less	9	25
		Just disqualified, score 2:		
101	29.8	Visual acuity	1	
62	17.0	Depth perception	1	
80	28.2	Exophoria at 6 meters	1	
19	19.9	Low convergence	1	
90	28.6	Hyperopia, 1 diopter, esophoria	1	
100	28.7	Hyperopia, 3 diopter	1	
16	18 6	Hyperopic astigmatism, corrected	1	7
		Disqualified, score 3:		
42	19.0	Visual acuity and hyperphoria	1	
83	21 7	Hyperopia, low accommodation	1	
91	27.8	Hyperopic astigmatism, low accommodation	1	3
		Disqualified, score 4: Hyperopic astigmatism, poor depth perception, with:		
55	15.6	Convergent strabismus	1	
46	Low.	Low visual acuity	1	
82	25 9	Deficient accommodation	1	3
		Disqualified, score 5:		
87	31.1	Hyperopia, exophoria, hyperphoria, low convergence and accommodation	1	
85	Low.	Hyperopic astigmatism, low visual acuity and depth perception, hyperphoria	1	
77	Low.	Hyperopic astigmatism, low visual acuity, depth perception and accommodation	1	3
		Disqualified, score 6:		
39	17.5	Myopia, corrected; low visual acuity, depth perception and convergence; exophoria		1
		Disqualified, score 8:		
63	Low.	Myopic astigmatism, strabismus, low visual acuity, accommodation and depth perception; impossible to measure convergence		1
		Total number of cases		59

SUMMARY OF CONCLUSIONS.

1. Measurements of retinal sensitivity made upon 101 subjects by a new method, previously described in detail, show individual differences far in excess of the accidental variations for the same individual and the same conditions.

2. The result of any one of as many as four consecutive series is of about equal reliability even with unpracticed subjects.

3. The distribution of the various results of retinal sensitivity measurement suggests a natural division of individuals into two groups, most numerous where the times of stimulation are approximately 27 and 16σ, respectively.

4. Correlation of the results of the first series with those of the second, taken immediately after the first, in 96 subjects, shows almost identical characteristics for the two. The correlation ratio is 0.857 ± 0.018.

5. The characteristic equation derived from correlation of the retinal sensitivity results (average of first and second series) with visual acuity indicate that retinal sensitivity

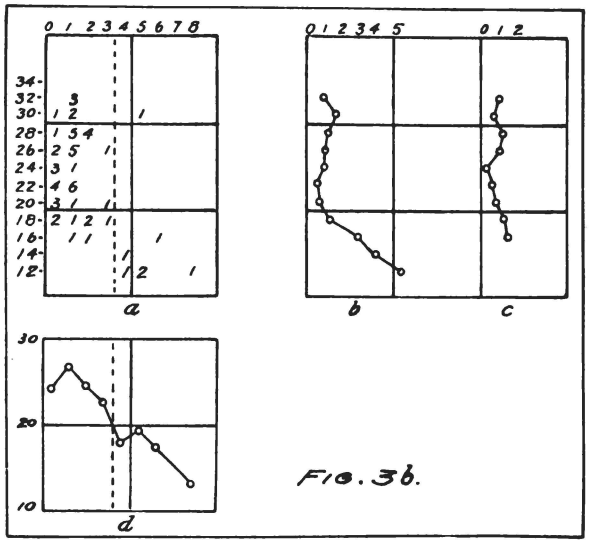


FIG. 3b.

is somewhat dependent upon the visual acuity of the eye with poor vision, but not upon that of the better eye unless the advantage of this latter is evident in enhanced binocular visual acuity.

6. Due allowance for the differences due to different visual acuity leaves individual differences in retinal sensitivity measurements unaccounted for almost to the original amount. The standard deviation from 4.64 is reduced only to 4.24 when correction is made for the differences due to different visual acuity.

7. Correlation between retinal sensitivity and a rating based upon the ophthalmologic portion of the Air Service medical examination for flying status indicate that in general no definite relation exists between retinal sensitivity and disqualification; except when the latter is based on findings which, in degree and character, indicate distinctly pathological conditions.

8. Incidentally, the method of correlation indicates that binocular visual acuity is dependent chiefly upon the eye which, used singly, shows the better vision, to the extent of nearly five times its dependence upon the eye with the poorer vision. This has exclusive reference to results obtained with the letter-chart.

APPENDIX.

The apparatus used in this work differedfrom that used in the former work in the substitution of a perforated and painted metal slip for the punched card formerly used for the test-stimulus aperture. It was found that simply drilling and painting the slip would not suffice, since the paint tended to thin itself, by its surface tension, at the margins of the aperture, causing a ring-shaped shadow by which a photometric balance between screen and aperture was rendered impossible.

The following will give an idea of the technic found necessary in preparing replaceable apertures free from such defect:

Sheet zinc of 0.017-inch thickness was found suitable for the purpose. The hole at the center was drilled to admit the end of a reamer (known to the trade as a "No. 1 taper pin reamer"), provided with a wooden sleeve adjusted so that the hole, reamed from the back until the sleeve just touches the metal, was of just the right size to fit a carefully sized gauge plug. This plug was made for the purpose and measured 0.1687 inch (4.285 mm.) in diameter. The margins of the aperture were then freed from burrs by passing a moderately fine file flat over the front and back surface of the metal.

Before painting the slips, the back of the hole was covered with surgeons' adhesive, and the hole filled with Alabastine (water) paint, mixed to a putty consistency. Beeswax was tried and worked almost as well. The filling was pared down flush with the face of the zinc by means of a clean-edged carpenter's chisel, and the face of the zinc cleaned free of excess filling material at the same time.

The face of the slip was then painted. Two coats of a good ordinary white oil paint were applied in the usual way, and as these nearly covered the metal, a coat of Alabastine white was applied. The filling was then removed by first stripping the adhesive from the back and locating the center of the hole by pricking with a needle, and then carefully punching the filling out from the face piecemeal, without touching the parts which would form the margins of the hole. After this the reamer was run into the hole from the back, as in the first place, carefully and *only* until the collar on the reamer lightly touched the zinc.

The object of this procedure was that the edge of the opening should be perfectly sharp, and that the surface of the face of the slip should continue to be plane accurately and exactly until it met the cylindrical (slightly conical) surface cut by the reamer. If carefully and successfully done, it was readily possible to make the aperture disappear by adjusting the brightness of the back screen.

Considerable care had to be used in handling the finished slips, as they were rendered useless by the slightest soiling or chipping of the paint at the margins of the aperture.

EXPLANATION OF TABLES.

Table I.

Measures of fluctuation of the result of a single series for three practiced subjects.

T=Threshold, on arbitrary scale, reduced to standard aperture (area=$10\sqrt{2}$ sq. mm.).

$\sigma(T/_M)$=Standard deviation, relative to the mean for like conditions.

E_T=Probable error, in terms of arbitrary units, as T.

The last three columns give the times corresponding to T, and $T \pm E_T$, respectively.

Table II.

Comparative values and variabilities of the results of four consecutive series: B, C, and L, are three practiced subjects; and the last row gives the results for 33 unpracticed subjects.

N=Number of series concerned in the average.

M=Mean of all values, relative to the mean of all series for the same subject.

MV=Mean variation expressed in the same terms as M. These values, multiplied by 1.253, should be comparable with the values of σ stated in the third column of Table I. The four series consumed an hour's time, more or less, according to the practice and natural aptitude of the subject.

Table III.

The results of correlation of retinal sensitivity (1) with visual acuity (2, 3, 4) measured with the Snellen letters under the conditions of the experiment. The results from the letter chart have been reduced to decimal values (e. g., 20/20=1.00; 20/15=1.33; $20/20+\frac{5}{8}=1.00+\frac{5}{8}\times 0.33=1.21$) and the values of σ in division *c* of the table are expressed in such decimal units. Retinal sensitivity is expressed in arbitrary scale units, the same as those in which T is elsewhere expressed.[5]

ss=Subscript indicating the variables involved and their interrelation.

N=number of cases involved.

r=correlation ratio.

σ=standard deviation.

FIGURES, LEGENDS.

(1) Distribution of 192 measurements of retinal sensitivity; the values obtained from the first and second consecutive series of each of 96 different subjects. Abscissæ are (T). Class interval =1. Class types are integral values +0.4. Ordinates are class frequencies.

(*a*) Crosses and solid line frequency by classes.

(*b*) Circles "sliding" averages of four class frequencies.

(*c*) Smooth curve closest fitting normal distribution.

Ten of a possible 202 measurements fail to appear in (*a*) and (*b*) owing to the fact that they were too low to be measures with the apparatus used. These were taken into account in computing the constants of the normal distribution (*c*). See text.

(2) The relation between the results of the first (I) and second (II) series, for each of 96 subjects. The oblique dotted line represents the condition of equality. Those plotted below this line gave a result on the second series lower than that of the first, and vice versa.

(3) The relation between retinal sensitivity measurements and the general degree of visual defectiveness found in the ophthalmologic examination.

(*a*) *Classified results.*—Ordinates indicate class as to retinal sensitivity. The class interval is 2 units on the scale, and the mean of the class is greater than the designation given by 1 unit; e. g., in the 30 class, the lowest possibly included is 30, the highest 31.99, the mean (or type of the class) therefore is 31 minus. Abscissæ points disqualification. See text.

(*b*) Average points of disqualification for each retinal sensitivity class.

(*c*) Same as (*b*), scores of 4 or over excluded.

(*d*) Average retinal sensitivity (ordinate) for each class as to points disqualification. The cases falling to the right of the dotted line in (*a*) and (*d*) are those excluded from (*c*).

—*By courtesy of the Journal of Experimental Psychology.*

[5] For a more complete explanation of the meaning of these symbols and of the methods of correlation see: Yule, An Introduction to the Theory of Statistics, fifth edition, London, 1919; Chap. IX ff, and Chap. XII.

PULSE RATE AND BLOOD PRESSURE RESPONSES OF MEN TO PASSIVE POSTURAL CHANGES. I.

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The development of the airplane has added interest to the circulatory responses of men following passive alterations of body position, for the aviator is subjected frequently to sudden variations in body position, which are largely passive as far as his musculature is concerned. Changes in pulse rate and blood pressure correlated with changes in body position made by the subject have been studied by many investigators, but the changes in circulation accompanying postural changes in which the subject is moved by some force outside of his body have not received the same attention.

In experiments on animals Hill (1895) showed that the blood pressure in the carotid artery was increased by tilting the animal from the horizontal to the head down position and decreased by tilting from the horizontal to the head up position. Barach and Marks (1913), working with young men 15 to 30 years of age, on a tilting table, concluded that "when the element of muscular effort has been eliminated, change of body posture from the erect to the horizontal will cause an increase in the maximum pressure, a decrease in the minimum pressure, and an increase in the pulse pressure." Henderson and Haggard (1918) followed the circulatory responses in the head down position of 10 young men on the tilting board, and report that "in the inverted or head down position (30 to 45°) the heart rate in 10 men was slower than in the flat position by an average of 9.5 beats a minute and slower than the erect position by 17."

Excepting two cases (in the tilt from the erect to the reclining position) all of the pulse responses were minus in the tilts which lowered the head and plus in those which raised the head. The responses in systolic and diastolic pressures were not so uniform. The systolic pressure of 5 of the 10 men and the diastolic pressures of all 10 fell on changing from the erect to the horizontal. On tilting from the horizontal to the head down position the systolic pressure rose in some cases and fell in others, the subjects being about equally divided between the two responses. The same was true of the responses to the return tilt; i. e., from the head down position to the horizontal. The diastolic responses following both of these tilts were also about equally divided between plus and minus. Although the work of Stephens (1904) is not strictly comparable with the preceeding articles because his subjects were not tilted except from the reclining to the head down position, his averages of the responses in pulse rate, and systolic pressure to changes in body position are interesting in this connection. These averages show a decrease in the per minute heart rate and an increase in the systolic blood pressure from the erect position, through the sitting and reclining positions to the head down position. Stephen's data were collected after the circulatory balance was reached by his subjects. More recently Barach (1919) summarizes the responses in pulse rate, systolic and diastolic pressure of 48 normal adults to two passive tilts. When these subjects were tilted from the standing position to the reclining he found that the pulse rate and diastolic pressure fell and the systolic pressure rose. Following the return tilt from reclining to standing position the pulse rate and diastolic pressure rose and the systolic pressure fell.

These observations collectively suggest that the circulatory responses of men to passive tilts which lower the head are a decrease in the per minute pulse rate, an increase in the systolic pressure (sometimes a decrease) and a decrease in the diastolic pressure (sometimes an increase).

The present study was undertaken at the Medical Research Laboratory of the Air Service with a view to obtaining additional data on the constancy of these responses of men to passive postural changes of various sorts and on the degree of these responses.

Fifty young men, 20 to 31 years of age, drawn from the Medical Department and from the Air Service of the Army, were used as subjects. Each man was given the routine physical examination by an internist and by an ear, nose, and throat specialist before selection for these tilt tests. No man not reported sound was taken. All of the subjects were familiarized with the tilting table and its operation before the tests were made, to eliminate the factor of surprise. During the tests the subject refrained from talking and the observers spoke only when necessary.

The tilting tests were made by two observers, one taking the pulse counts and the other the blood pressures throughout the test. The subject was placed on the tilting table and swung up into the horizontal plane, here termed the "reclining position," after the blood-pressure apparatus was attached to the left arm (a Tycos apparatus was used and the readings taken by auscultation) the subject was undisturbed 10 minutes, when the first records of pulse and blood pressure were taken simultaneously. Three readings were made and the averages taken as the normals against which the subsequent readings in other positions were checked. As soon as the normals were established the subject was tilted quickly and quietly into the new position and a new reading taken. As assistants were always present to look after the mechanical side of the tilting, the observers were able to make the first count of pulse rate and the first measurements of

blood pressure within 30 seconds after the tilt. These figures have been recorded in the tables as the "immediate response." After the immediate response was recorded the subject was again undisturbed for five minutes. At the end of five minutes a second set of records was taken which has been termed the "response at the end of the fifth minute." These readings completed, the subject was tilted to the next position and the process repeated. Effort was made to take all readings at the end of expiration, but this was not always possible. From these several sets of readings, the amount and direction of change in the pulse rate and blood pressures during the first 30 seconds after the body position was altered, the amount and direction of change at the end of the fifth minute, and the amount and direction of change during the five minutes in each position were obtained. In establishing these values the readings in a given position were compared with those taken at the end of the fifth minute in the preceding position. Five-minute intervals were chosen because it was found by preliminary tests in which minute to minute readings were taken that the subjects generally reached their maximum responses and adjustments to the new position within the first three minutes after the tilt was made.

Two series of tilts were used. In the first series the subject was tilted from the reclining position to head up 45°, head up 45° to standing, standing to reclining, reclining to standing, standing to head down 45°, head down 45° to standing. In the second series the first three changes of position were identical with the first three of the first series, i. e., from reclining through head up 45° and standing to reclining again. Then followed tilts from reclining to head down 45° and head down 45° to reclining. (See Fig. 1c.)

GENERAL RESPONSES.

Considering the responses in pulse rate, systolic pressure, and diastolic pressure separately, correlated only with the changes in the position of the subjects, the responses in pulse rate were the most uniform of the three. Ninety per cent of all cases in which the head was elevated during the tilt showed an immediate rise in pulse rate, and 84 per cent had a higher pulse rate at the end of the fifth minute after a tilt which elevated the head than at the end of the fifth minute in the previous position. The opposite tilts, those in which the head was lowered, gave much the same grouping of cases, with the opposite pulse response. Ninety-one per cent showed an immediate fall in pulse rate on lowering the head, and 86 per cent had a lower pulse rate at the end of the fifth minute than in the previous position. The predominate pulse responses, therefore, to all changes of position taken collectively were (1) an increase in pulse rate—plus response—on raising the head, and (2) a decrease in pulse rate—minus response—on lowering the head. All of the several types of tilts produced these responses, as from 62 to 100 per cent of the cases in each tilt gave the responses designated above as the predominate responses. In the main these predominate responses were supported by larger percentages immediately after the tilt was made than at the end of the fifth minute, suggesting that the pulse response was compensatory to the sudden change in position of a considerable volume of blood by gravity, and that additional responses during the next five minutes completed the adjustments to the new body position. This is confirmed by the changes in blood pressure during the five-minute interval. In some of the tilts these readjustments amounted to a change in the character of the blood-pres-

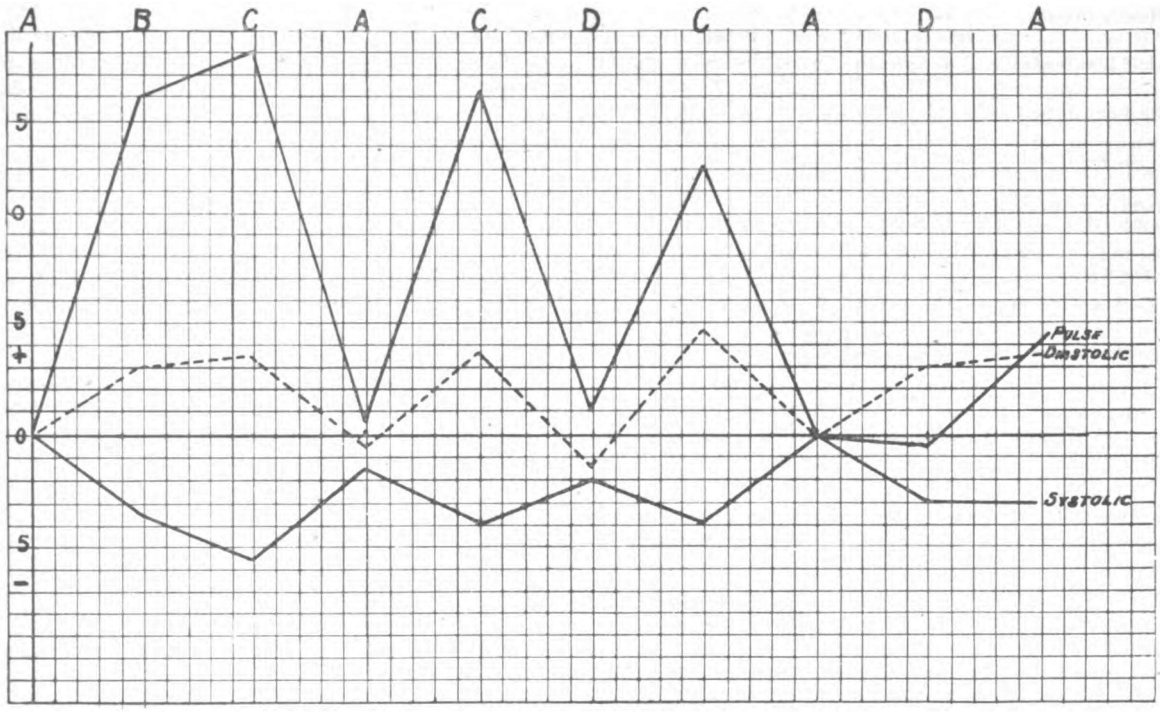

FIG. 1c.—Average deviations in pulse rate, systolic pressure, and diastolic pressure from the reclining normals at the end of the fifth minute after each tilt. Tilts plotted in sequence used in the tests. Pulse rate plotted in beats per minute and blood pressures in millimeters of mercury. A, reclining; B, head up 45°; C, standing; D, head down 45°.

sure response from minus to plus. Although in other tilts this shifting of blood pressure was not so profound, in all tilts excepting that from head down to standing more of the subjects showed a zero blood-pressure response at the end of the fifth minute than immediately after the change of position (Table 1).

TABLE 1.—*Responses to tilts.*

Tilt.	Cases.	Pulse.			Systolic.			Diastolic.		
		Rose.	Held.	Fell.	Rose.	Held.	Fell.	Rose.	Held.	Fell.
All tilts raising head..	244	*90*	5	5	17	9	*74*	*58*	7	35
		84	5	11	21	21	*58*	*60*	20	20
All tilts lowering head.	108	8	1	*91*	*48*	9	43	18	8	*74*
		6	8	*83*	*48*	13	39	24	9	*67*
Head down to reclining.	46	*79*	4	17	38	22	38	34	22	*44*
		69	14	17	38	18	*44*	*47*	23	30
Head down to standing.	32	*100*	0	0	33	0	*67*	*67*	0	33
		100	0	0	17	17	*67*	*83*	0	17
Reclining to head up 45°.	58	*100*	0	0	4	4	*92*	*82*	4	14
		100	0	0	18	14	*68*	*76*	10	14
Reclining to standing..	50	*100*	0	0	12	8	*80*	*68*	4	28
		100	0	0	20	24	*66*	*68*	24	8
Head up 45° to standing.	58	*79*	17	4	14	7	*79*	41	4	*55*
		62	7	31	18	27	*55*	*41*	24	35
Reclining to head down 45°.	34	17	0	*83*	12	12	*76*	35	12	*52*
		12	17	*71*	24	12	*64*	*59*	17	24
Standing to reclining..	42	5	0	*95*	*76*	0	24	14	5	*81*
		5	5	*90*	*71*	5	29	19	5	*76*
Standing to head down 45°.	32	0	6	*94*	*50*	19	31	19	0	*81*
		0	0	*100*	*50*	25	25	19	6	*75*

Data given in per cents for direct comparison. First line in each pair gives the immediate response as compared with the normal in the previous position; the second line gives the response at the end of the fifth minute after the tilt.

The blood-pressure responses were not so sharply grouped as were the pulse rate changes. The predominate responses in general, as indicated by the highest percentages, were a fall in systolic pressure and a rise in diastolic pressure following those tilts which raised the head, and a rise in the systolic pressure and a fall in the diastolic pressure following those tilts which lowered the head. The diastolic pressure varied in the same direction as the pulse rate and the systolic pressure in the opposite direction. The predominate blood-pressure responses were supported by much smaller percentages than were the changes in pulse rate. In several of the tilts the cases were about equally divided between plus and minus blood-pressure responses, indicating that the blood-pressure responses were much less constant than the pulse rate changes.

Three separate tilts did not follow the predominate responses of blood pressure as determined by the mass data of all classes. In the reclining to head down tilt the systolic responses of 76 per cent of the cases were minus immediately after the tilt, and 64 per cent held a systolic pressure lower than the reclining normal to the end of the fifth minute. The diastolic pressures of 52 per cent also fell below the reclining value immediately after the tilt (the response expected from the predominate responses of the mass data of head lowered tilts), but in 59 per cent of the cases of this tilt the diastolic pressure rose during the five-minute interval above the reclining normal. In the reclining to head down tilt, therefore, the pulse response followed the typical response of all head down tilts, the systolic pressure fell instead of rising and the diastolic pressure fell as expected immediately after the tilt but rose above the reclining value during the next five minutes.

The other two exceptions to the predominate responses of the mass data were in the diastolic pressure responses. In both the head down to reclining and head up 45° to standing tilts, the immediate diastolic response was a fall in pressure below the former value, followed by a rise during the next five minutes. The diastolic exceptions in all three tilts, therefore, were all of one type, an initial fall regardless of the position from which the tilt was made, followed by a rise above the value in the preceding position during the next five minutes. It is to be noted also in this connection that in each of the three tilts in which the diastolic pressure did not follow the predominate response of the mass data, the cases of each tilt were about evenly divided between plus and minus response. As is shown under the discussion of the degree of change, in these three tilts the actual amount of change in pressure measured in millimeters of mercury was slight and the diastolic pressures in these three tilts may represent indifferent responses.

If the predominate responses in pulse rate, systolic pressure, and diastolic pressure, as determined in Table 1 by the largest percentage of cases in each tilt group, be summarized in a formula (P=pulse, S=systolic pressure, D=diastolic pressure), P+S−D+ represents the predominate responses of the largest per cent of cases to a passive tilt in which the head was raised, regardless of the initial position from which the tilt was made. Similarly, P−S+D− represents the predominate responses of cases in which the head was lowered, excepting the tilt from reclining to head down. In this tilt the largest per cent of cases gave the P−S−D+ responses.

These three formulæ of responses from the mass data were applied to the actual records of each individual case to determine the degree of correlation existing between the three responses of pulse rate, systolic, and diastolic pressures. The responses at the end of the fifth minute after the tilt were used (Table 2). Only one-third of all cases in which the head was elevated during the tilt gave the expected responses in all three variables, pulse rate, systolic and diastolic pressures. In the tilts lowering the head the percentage was slightly higher but still below 50 per cent. In only two tilts did the percentages of cases agreeing with the formula of responses exceed 50 per cent in the head down to standing tilt and in the reclining to head up 45° tilt. Cases giving any two of the predicated responses were more numerous, including 59 per cent or more of the subjects in each tilt with the exception of the head down to reclining tilt. A comparison of the cases giving any two of the expected responses suggests that there is little difference in the constancy of the systolic and diastolic blood pressures, as the PS and PD groups were about the same. Fewer subjects gave both of the predicted blood-pressure responses than gave the predicted pulse and either one of the blood-pressure responses. This was excepted from the summary of the mass data (Table 1) as the pulse rate changes were the most constant of the three responses. This confirmation of the grouping in Table 1 gives added value to those percentages, which show not only the relative constancy of each response but also that the predominate method of compensation was a change in pulse rate.

TABLE 2.—*Correlations of the three responses, pulse rate (P), systolic pressure (S), and diastolic pressure (D).*

[Data in per cent of cases giving responses indicated.]

Tilt.	P+S−D+.	P+S−.	P+D+.	S−D+.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
Head down to reclining	13	30	39	26
Head down to standing	67	67	83	67
Reclining to head up 45°	55	72	70	55
Reclining to standing	32	50	56	32
Head up 45° to standing	21	48	27	30
All head-up cases	33	52	50	38
	P−S+D−.	P−S+.	P−D−.	S+D−.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
Standing to head down	31	50	70	31
Standing to reclining	38	57	62	43
	P−S−D+.	P−S−.	P−D+	S−D+.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
Reclining to head down	47	58	53	47

It is evident from Table 2 that the responses to changes in position were not equal in the three variables, pulse rate, systolic pressure, and diastolic pressure, and that there was no stereotyped response which included the majority of cases. Satisfactory compensations, at least such as would maintain the individual for five minutes without loss of consciousness (none of the subjects fainted during the tilts), were made by other combinations of pulse, systolic and diastolic responses than those expected from the mass data.

DEGREE OF RESPONSE.

In Figure 1 the mean values of change in pulse rate per minute and blood pressure in millimeters of mercury have been plotted, taking the several tilts in the sequence in which they were made on the subject. The mean values were obtained after the actual values of all individual cases had been plotted by classes. As the pulse-rate counts were made in 20-second units and multiplied by 3, a deviation of plus or minus one count by the observer has been allowed, and similarly a deviation of plus or minus one unit (2 millimeters) on the Tycos dial has been allowed in the blood-pressure readings. The zero class of the pulse values included, therefore, all cases whose responses varied from plus three beats to minus three beats per minute and the zero classes in the blood pressures all from minus 2 millimeters to plus 2 millimeters. The class ranges for pulse rates were nine beats per minute and for blood pressure 6 millimeters of mercury.

The tilts from reclining to head up 45° and from reclining to standing gave almost identical degree changes, being P+16 beats, S−3.5 millimeters, D+3 millimeters, and P+16, S−4, D+3.5 respectively at the end of the fifth minute after the tilt. When the standing position was reached by two tilts, i. e., reclining to head up 45° and head up 45° to standing, greater deviation from the reclining normals of pulse rate, systolic and diastolic pressures were obtained, the responses at the end of the fifth minute of standing after these two tilts being, P+18, S−5.5, D+3.5. These values equal or exceed each of the three responses to either the reclining to head up 45° tilt, or the reclining to standing tilt. When the standing position was reached by one tilt from the head-down position, i. e., the head-down to standing tilt the pulse response was smaller and the diastolic response greater than either of the other two standing values. The response at the end of the fifth minute of standing after the head-down to standing tilt were P+12, S−2, D+6, and the deviations from the reclining normals P+13, S−4, D+4.5.

In the reverse tilts, standing to reclining, opposite responses obtained, P−17.5, S+4, D−4, so that the readings at the end of the fifth minute in the reclining position were almost identical with the normals taken in the reclining position. In the standing to head-down tilt the response in pulse was not as great as in the standing to reclining tilt, being P−15, S+2, D−5. Although less than the responses from standing to reclining, these values following the standing to head-down tilt are fairly close reverse responses to those following the head-down to standing tilt. The responses after that tilt were P+12, S−4, D+4.5. It is evident that a subject does not relax as completely in the unusual position of head down 45° as in the reclining position, and the factor of muscular effort, either conscious or unconscious, is not completely eliminated in the head-down position. Similarly a certain amount of muscular effort on the part of the subject can not be avoided in the standing position even though the subject is brought to this position by forces outside of his body. In the head-down to standing tilt, therefore, the muscular effort of the subject and the movement of the blood by gravity both contributed to the reactions of the subject.

In order to ascertain the responses to the head-down position following a tilt from a position in which the muscular effort of the subject was eliminated as far as possible, part of the subjects were tilted from the reclining to the head-down position and then back to the reclining position. The responses at the end of the fifth minute in the head-down position following the reclining to head-down tilt were quite different from those at the end of the fifth minute in the head-down position following the standing to head-down tilt. Following the reclining to head-down tilt the deviations from the reclining normals were P−0.5, S−4, D+3 at the end of the fifth minute as compared with P+1, S−2.5, D−1.5 at the end of the fifth minute after the standing to head-down tilt. After the return tilt, head down to reclining, the subjects did not return to the reclining normals in five minutes, the average deviations from the reclining normals being P+4, S−2,5, D+3.5.

From these various degree values it seems that the subjects examined made rather complete adjustments in five minutes to tilts in the reclining-standing quadrant, as the changes in pulse and blood pressure in one direction are offset by approximately equal changes in the opposite direction on reversing the tilt. In the reclining to head-down quadrant the responses were much less uniform, and the circulatory balance was probably not established in the five-minute interval. Tilts starting in the reclining-standing quadrant and ending in the reclining head-down quadrant, or vice versa, gave more uniform and also more profound responses than tilts in the reclining head-down quadrant alone. These tilts, however, which carried the

subject through more than 90°, showed the disturbing effect of the head-down position, either at the beginning or the end of the tilt, upon the general compensations of the body to changes in position.

Considering the mass data of all cases collectively the responses obtained from these 50 men were in general the responses expected from the review of previous experimentation. The formulæ P+S−D+ for the tilts raising the head and P−S+D− for those lowering the head, included the largest percentages of responses in all tilts excepting the reclining to head down tilt, the mass responses of which were P−S−D+. The application of these formulæ, however, to the individual cases showed that a relatively low per cent of the individuals actually gave three responses simultaneously and that these formulæ were therefore unreliable for the study of individual subjects even among men who had been pronounced in good physical condition. The response to passive changes in body position as evidenced by the data here offered, was primarily one of change in pulse rate. The blood pressure responses were much more subject to individual variation in the general adjustment following these passive body position changes, although the blood pressure responses did show definite groupings in the mass data. As the effect of the shifting suddenly of a quantity of blood by gravity could produce through its effect on the nervous mechanism controlling the heart, changes in pulse rate such as followed the changes in body position, and as several other factors are involved in the blood pressure changes, a greater constancy of the pulse responses might be expected.

The responses in systolic pressure to the reclining to standing tilt were so different from those given by Crampton (1913) for healthy men on standing from the reclining position that the mass data may be reviewed here for comparison. Crampton states "that in the perfectly normal there occurs upon rising from the recumbent position a vasoconstriction effort which squeezes these veins (splanchnic) and raises the blood pressure, which more than overcomes the hydrostatic load." In the tilt from reclining to standing the mass response was a fall in systolic pressure, supported by 80 per cent of the cases immediately after the tilt, and by 66 per cent at the end of the fifth minute, instead of the rise in systolic pressure found by Crampton in the men who stood voluntarily. As the subjects used in these tilting tests had been reported sound by the examining surgeons the vasomotor tone of the subjects was presumably good. The fall in systolic pressure following the tilting of these men from reclining to standing suggests either a lag in this compensatory vasoconstriction effort or a greater demand for compensation than could be met by the splanchnic area alone. As the per cent of cases giving the fall in systolic pressure fell during the five-minute interval from 80 to 66 per cent there was some compensation which raised the blood pressure during the five-minute period in at least 14 per cent of the cases. In the case of the individuals rising by their own muscular efforts the tightening of various muscles of the body which would occur in the act of rising, would in part prevent the fall in pressure which took place in the reclining subjects who were suddenly tilted into the standing position. The relative demand, therefore, for compensation from the splanochnic vessels would be greater in the case of the tilted subjects than in that of the subjects rising by their own muscular effort.

SUMMARY.

1. In general tilts elevating the head gave a rise in pulse rate, a fall in systolic pressure and a rise in diastolic pressure, and those lowering the head a fall in pulse rate, a rise in systolic pressure, and a fall in diastolic pressure. The conspicuous exception to these responses was the reclining to head down tilt in which the largest per cent of cases gave a fall in pulse rate, a fall in systolic pressure, and a rise in diastolic pressure.

2. The individual data showed that only a little over one-third of all cases gave the three responses in pulse rate, systolic and diastolic pressures expected from the mass date, simultaneously.

3. Tilts from reclining to head down 45 degrees and return gave the least constant responses of all the tilts used.

4. The tilt from reclining to head up 45 degrees produced almost the same degree of responses as the tilt from reclining to standing.

5. With the exception of the tilts in the head down to reclining quadrant the responses given to any tilt were offset by approximately equal opposite responses when the tilt was reversed.

6. The initial and final positions of the subject had more effect on the degree of responses following a tilt than did the distance travelled by the subject during the tilt.

The writer wishes to acknowledge his obligations to Lieut. Harry Fried, M. C., who assisted in a large number of these tilting tests.

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PULSE RATE AND BLOOD PRESSURE RESPONSES OF MEN TO PASSIVE POSTURAL CHANGES. II. UNDER LOW OXYGEN.

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Fifteen men from the Air Service and the Medical Corps of the United States Army were used as subjects in these tests. The changes in position were made by means of a tilting table and with little or no muscular effort on the part of the subject. The pulse rate and blood pressures taken after 10 minutes reclining constituted the normals on which the comparisons were based. Low oxygen conditions were obtained in two ways, by rebreathing and in the low-pressure chamber.

The data collected showed:

1. The responses under low oxygen were of the same type as those made by the subject at sea level, until the lack of oxygen became so severe that collapse was imminent.

2. The actual amount of change in pulse rate and blood pressure varied slightly from the sea-level responses until 10,000 feet equivalent altitude was exceeded.

3. Above 10,000 feet equivalent altitude the responses were more profound than those at sea level, the differences in pulse rate being the most noticeable. These responses increased as the equivalent altitude was increased.

4. Just before collapse from low oxygen the passive changes in position failed to bring about large changes in pulse and blood pressure, the tendency being for all three, i. e., pulse, systolic and diastolic pressures, to fall when the subject was tilted.

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